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DEMONSTRATION OF A LEACHATE TREAMENT PLANT

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This interim report presents the results of start-up and operations experience during the first year of a demonstration grant project entitled "Demonstration of a Leachate Treatment Plant". The plant is designed to provide a variety of chemical/physical and biological treatment sequence options. The chemical/physical units include lime precipitation, sedimentation, air stripping, neutralization and nutrient supplementation. These treatment processes are designed to remove heavy metals, ammonia and organic materials, and to encourage subsequent biological treatment by reducing pH and adding the nutrient phosphorus. The biological treatment process is activated sludge. Treatment of leachate from a lined sanitary landfill is accomplished in this facility to permit discharge to the Delaware River.

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DEMONSTRATION OF A LEACHATE TREATMENT PLANT

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Summary and Conclusions

The results of the operation of a full-scale sanitary landfill leachate treatment plant are reported. The plant is designed to provide a variety of chemical/physical and biological treatment sequence options. The chemical/physical units include lime precipitation, sedimentation, air stripping, neutralization and nutrient supplementation. These treatment processes are designed to remove heavy metals, ammonia and organic materials, and to encourage subsequent biological treatment by reducing the pH and adding the nutrient phosphorus. The biological treatment process is activated sludge. The demonstration leachate treatment plant is designed to provide operational flexibility in that the flow can be directed through the various unit processes and operations in any sequence.

The purpose of this project is to demonstrate the efficiency of a number of treatment sequences. Specifically, five modes of operation have been defined and are being investigated. System 1 consists of chemical/physical treatment followed by activated sludge; System 2, chemical/physical treatment only; System 3, biological treatment followed by chemical/physical; System 4, biological treatment only; System 5, bench-scale studies, including activated carbon adsorption treatment.

Data have been collected which can be used to characterize the quality of raw leachate generated in an operating sanitary landfill. These data show that the leachate from this sanitary landfill source is high in organic matter (average COD/liter of 11,210 mg., average BOD_5/liter of 4,460 mg) and nitrogen (average NH_4^+ = N/liter of 1,503 mg). The raw leachate heavy metals concentrations are somewhat lower than expected, possibly reflecting the relatively high pH of the leachate. (Note that all data have been collected with non-filtered samples.)

High concentrations of ammonia in the raw leachate exceed the plant's effluent criteria and are sufficient to inhibit the growth of the activated sludge microorganisms. For this reason the original plant design has been augmented with an ammonia air-stripping lagoon.

System 5 studies have been conducted for a number of purposes. Bench-scale tests have provided optimal operating data for chemical/physical units. In particular, System 5 has provided data for the development of lime, sulfuric acid and phosphoric acid dosages.

Activated carbon adsorption has been evaluated as a treatment method for raw leachate. For raw leachate, carbon adsorption did not prove to be an effective treatment procedure. The inability to use carbon adsorption is the result of high suspended solids loading causing increased pore plugging and the wide range of flow variability.

Systems 3 and 4, those in which raw leachate is influent to the biological units, have received considerable operating attention. The preliminary results indicate that the raw leachate is not directly treatable by biological means. The operating experience shows that an activated sludge can not be developed on raw leachate. The failure to develop activated sludge is attributed to the nutrient imbalance caused by a lack of phosphorus and to an inhibition caused by toxic levels of ammonia.

Systems 1 and 2 are those in which the raw leachate is treated first by chemical and physical means. The results of these systems are most promising. Lime precipitation followed by sedimentation has been successful in removing the heavy metals and a portion of the organic matter. Specifically, this sequence has removed about one-third of the dissolved solids and nitrogen; one-half of the organic matter; three-quarters of the suspended solids; and ninety percent of the phosphates. The sequence has been successful in removing the heavy metals including one-third of the cadmium; one-half of the chromium and nickel; two-thirds of the lead and mercury; three-quarters of the copper; and over ninety percent of the iron and zinc.

An air stripping lagoon is included in the chemical/physical treatment sequence because of the excessive ammonia levels in the raw leachate. During the lime precipitation/clarification/air stripping mode of operation, the following removal efficiencies have been achieved: 56-57 percent BOD and COD; approximately 60 percent of the ammonia-N and total Kjeldahl-N; approximately 67 percent of the suspended solids; 50-65 percent of cadmium, nickel and mercury; 70-80 percent of chromium and copper; approximately 88 percent of lead; approximately 95 percent of zinc; and approximately 99 percent of iron.

The lagoon has a detention time of ten days, thereby providing an equalizing effect. That is, the effect of the lagoon is to dampen the peaks and to minimize shock loadings on subsequent treatment units. For example, during the period in which the lagoon was included in the treatment sequence, the 99 percent confidence interval for ammonia in the raw leachate was 241-1285 mg/liter; while during the same period the lagoon effluent 99 percent confidence limit was 210-425 mg/liter. Thus, the equalization effect is significantly beneficial in terms of lessening shock loadings.

System 1 has provided the best degree of treatment to date. This sequence consists of lime precipitation/clarification/air stripping/ neutralization/phosphorus addition/activated sludge. In this operational configuration, excellent removal efficiencies have been observed following the adaptation of the activated sludge to the waste. In all cases except NH_4-N, these effluent concentrations comply with the effluent criteria developed by the Pennsylvania Department of Environmental Resources and the Delaware River Basin Commission for discharge to the Delaware River. A summary of the data is presented in Table 1.

TABLE 1

SUMMARY OF SYSTEM 1 OPERATION DATA

Parameter	Raw Leachate mg/l	Final Effluent mg/l	Percent Removal	Discharge Standard mg/l
Ammonia-N	510	46.5	90.9	35
BOD_5	4993	60.5	98.8	100
Cadmium	0.049	0.014	71.4	0.02
Chromium	0.105	0.075	28.6	0.1
COD	9689	576	94.1	*
Copper	0.313	0.078	75.1	0.2
Iron	205	0.96	99.5	7.0
Lead	0.545	0.12	78.0	0.1
Mercury	0.015	0.004	73.3	.01
Nickel	0.52	0.27	48.1	*
Zinc	3.64	0.44	87.9	0.6

*No discharge standard for this parameter.

DEMONSTRATION OF A LEACHATE TREATMENT PLANT

R.L. Steiner, J.D. Keenan, and A.A. Fungaroli

I. INTRODUCTION

The potential for water pollution from sanitary landfill sites has become recognized in recent years. A number of studies[1-16] have documented the great pollutional strength of landfill leachates. The quality of this material varies with landfill age, nature and moisture content of the wastes disposed at the site, and hydrologic and soil factors. In spite of this variability, it can be stated that, especially for young landfills, the values of the critical sanitary parameters of leachate are at least an order of magnitude greater than for domestic sewage. The deleterious consequences following contamination of ground and/or surface waters by leachate may be severe, and it is for this reason that leachate treatment is receiving attention.

Solid waste consists of matter which can be decomposed by bacterial or microbial action, as well as of materials which are inert to microbiological activity. Some of the compounds, cellulose in particular, are resistant to biological breakdown, but with sufficient time decomposition will occur. Because of this resistivity and necessity to acclimatize the biological system, the chemical characteristics of leachate are time-dependent. To complicate treatment, as the paper decomposes, some of the inorganic ions which are bound to the organic matrix are released and can be removed by water percolating through the landfill. The actual mechanism of removal varies with the component but includes solution as well as colloidal transport.

The generation of leachate in landfills is complicated and cannot be generalized simply as surface water percolating through the sanitary landfill. When refuse is placed in the landfill, decomposition begins to occur. Some decomposition products may be water soluble whereas the parent products might not have been. This is especially true of cellulose. In addition, the inorganic constituents also must be considered since they vary with the state of decomposition. The amount of water percolating through a sanitary landfill is the primary control of leachate quality, but the chemical characteristics of the leachate are dependent on other parameters, including temperature, waste composition, moisture content, time, mode of decomposition (aerobic, etc.) and the amount of infiltration of rainfall at the landfill.

Recent studies have shown that leachate is produced in a sanitary landfill when the precipitation exceeds the net evapotranspiration of the region. Remson, Fungaroli, and Lawrence developed a model for predicting the movement of leachate through a sanitary landfill.[1] Further results using this model have substantiated the validity of the approach and prediction of leachate generation patterns is reasonably accurate.

Ground and surface waters can be protected if the landfill is underlain with an impervious membrane. With proper design, leachate is then directed toward collection points. A waste such as this, which is properly considered an industrial waste, must be treated prior to surface discharge. The leachate treatment state-of-the-art is still embryonic, although a few small scale studies have been conducted. These have demonstrated that neither conventional chemical treatment nor biological treatment can achieve the high degree of treatment efficiency expected today. Consequently, although we know that the pollution potential of sanitary landfill leachate can be avoided by interception using impervious liners, we are not yet able to define the optimum sequence of unit operations and processes required for adequate wastewater renovation.

The U.S. Environmental Protection Agency, Office of Solid Waste Management Programs, has awarded demonstration grant (S-803926) to investigate the effectiveness of alternative treatment sequences as employed at the full-scale facility in Falls Township, Pennsylvania. A 380 liter per minute (0.144 gpd) plant had been constructed to treat leachate from the GROWS (Geological Reclamation Operations and Waste Systems, Inc.) landfill. This project has as its primary goal the evaluation of the technical feasibility, operational efficiency and cost effectiveness of four alternative treatment sequences. These are: (1) chemical/physical followed by biological; (2) chemical/physical alone; (3) biological followed by chemical/physical; and (4) biological alone. The chemical/physical processing includes precipitation of heavy metals by lime addition, sedimentation, air stripping of ammonia and neutralization using sulfuric and/or phosphoric acids. Biological treatment consists of conventional activated sludge. Additional objectives of the study are the bench-scale evaluation of carbon adsorption on both raw and unit process effluents; and bench-scale testing to determine chemical dosage, sludge return rates, aeration rates and other plant operating criteria.

II. OVERVIEW OF LEACHATE TREATMENT OPTIONS

The purpose of this chapter is to review the literature regarding the composition of sanitary landfill leachates and their treatment. In brief, the character and variability of the leachate dictates the types of treatment systems which will be effective. The contaminants of greatest concern fall into several groups. The first group is the organic chemicals, important primarily because they exert an oxygen demand on receiving waters which may result in a depletion of dissolved oxygen deleterious to aquatic life. The second major group of contaminants found in sanitary landfill leachates is comprised of the heavy metals. As a group, these elements are of concern because they are toxic at sufficiently high concentrations. It is conventional practice to chemically characterize wastewaters such as leachate in terms of a number of other parameters. These are used for a variety of purposes including design, operational control, and evaluation of pollution potential.

LEACHATE COMPOSITION

In 1932, one of the first studies indicating that the disposal of solid waste could cause environmental pollution was reported by Calvert[2], who investigated the liquid waste from a garbage reduction plant in Indianapolis. In this process the garbage was cooked and the grease removed to produce fertilizer and animal feed, and the liquid waste was discharged into an impounding pit or lagoon. An analysis of this liquid is presented in Table 2, Column 1. Calvert analyzed the groundwater from existing wells surrounding the lagoon and found that wells up to 500 feet downstream of the site showed a marked increase in magnesium, calcium, total dissolved solids and carbon dioxide.

Carpenter and Setter[3], working at New York University in 1940, conducted one of the earliest studies concerned with landfill leachate. Auger holes were drilled through an existing landfill of undetermined age into the subsoil. Twenty-eight samples of leachate which were collected in the bore holes were analyzed chemically. The range of concentrations is presented in Table 2, Column 2. These results showed a wide variation of concentration over the site, thus indicating the difference of filled materials at various locations, or the differences in the age of the refuse at different points. Analysis of groundwater in the area was not performed, therefore the effect on the subsurface environment was undefined.

The first comprehensive research study of sanitary landfills under controlled conditions was conducted at the University of Southern California[4]. Test bins, simulating landfill conditions, were constructed. Water was added to simulate the infiltration of 1.12 m and leachate was collected and analyzed. Table 2 gives the minimum and maximum (Column 3) values of the initial (first 45.9 liters of leachate per cu m of compacted refuse) leachate. The most rapid removal (the highest concentrations) occurred with the first 232 liters per cu m of refuse. Thus, it

was postulated that removal would continue for many years but at a very slow rate, and it was considered unlikely that all the constituents would ever be removed.

The same study also examined a field site consisting of 2.4 m of refuse and 0.61 m of cover material. The refuse was in intermittent contact with the groundwater, analysis of which showed increases in all organic ions and a maximum biochemical oxygen demand of 125 mg/liter. One conclusion of the study was that the dissolved inorganic ions entering the groundwater through intermittent contact would decrease in concentration as a result of dilution and adsorption and travel in the direction of the groundwater movement.

The other conclusions reached in this study are summarized as follows: (1) A landfill, if located so that it is in intermittent or continuous contact with ground water, will cause the ground water in the immediate vicinity of the landfill to become grossly polluted and unfit for domestic or irrigational use; (2) dissolved mineral matter, entering ground water as a result of intermittent and partial contact of a landfill with the underlying ground water will have its greatest travel in the direction of flow, undergo a vertical diffusion to a limited extent, and be subject to dilution, the result of which will be a minimizing of the effect of the entering pollutant ions; (3) a landfill, if located so that no portion of it intercepts the ground water, will not cause impairment of the ground water for either domestic or irrigational use; (4) rainfall alone (in the area of this study) will not penetrate a 2.3 m thick landfill sufficiently to cause entry of leachate into the underlying ground water.

Longwell[5] stated in 1957 that an appreciable proportion of refuse could be extracted by water to produce a leachate rich in organic matter, inorganic salts (ions), and bacteria. The analysis of a surface leachate obtained from an unnamed landfill is given in Table 2 (Column 4).

In 1961 the British Ministry of Housing and Local Government conducted extensive research on the placement of landfills above the groundwater table (which they called "dry tipping"), and the placement of landfills below the groundwater table (which they called "wet tipping")[6]. In the "wet tipped" experiment the refuse was completely submerged and the horizontal groundwater flow rate was equivalent to 138 liters per sq m per day. The leachate quality is included in Table 2 (Column 5). Analyses of the groundwater before and after contact with the refuse are given in Table 3. These results show the considerable extent of groundwater quality degradation due to pollution by leachate.

In 1965 Qasim[7] studied the seepage waters from simulated landfills at the University of West Virginia. Three concrete cylinders 0.9 m in diameter and 1.2, 2.4, and 3.7 m in height were filled with municipal

Table 2. THE STRENGTH OF RAW LEACHATES*+

Parameter	(1)	(2)	(3)	(4)	(5)	Average Age of Fill Material 0.5 yr. (6)	6 yr. (7)	17 yr. (8)	(9)	(10)	Range 1 (11)	Range 2 (12)	Range 3 (13)
Acidity, as $CaCO_3$	3,000-3,300	100-9,450	-	-	-	-	-	-	-	-	-	-	-
Alkalinity, as $CaCO_3$	-	25-4,000	730-9,500	-	-	3,255	4,159	1,001	-	2,600-23,000	0-20,850	142-3,520	560
Aluminum Oxide	874	-	-	-	-	-	-	-	-	-	-	-	-
Ammonia N	-	-	0.2-480	54	700	-	-	-	177	-	0-1,106	1.4-1,028	155
Arsenic	-	-	-	-	-	4.31	0.1	4.6	-	-	-	-	-
Barium	-	-	-	-	-	8.5	0.8	0.3	-	-	-	-	-
BOD 5	-	6-7,330	-	975	7,745	-	-	-	-	41,000-180,000	81-33,360	3.9-57,000	6,300
BOD 20	-	-	21,700-30,300	-	-	54,610	14,080	225	-	-	-	-	-
Cadmium	-	-	-	-	-	-	-	-	-	-	0.03-17	-	-
Calcium	66.3	-	240-2,330	-	-	-	-	-	-	-	60-7,200	76-3,900	550
Carbon, Total Organic	-	-	-	-	-	-	-	-	-	-	256-28,000	70-27,700	3,600
Chloride	2,950	280-12,300	96-2,350	128	2,000	1,697	1,330	135	2,340	-	4.7-2,467	60 2-2,467	470
COD	-	-	-	-	-	39,680	8,000	40	50,715	-	40-89,520	31.1-71,680	8,000
Copper	-	-	-	-	-	0.05	0.05	0.05	5.0	-	0-9.9	-	-
Cyanide	-	-	-	-	-	0.024	0.005	0.02	-	-	-	-	-
Dissolved Oxygen	-	0-5.6	-	-	-	-	-	-	-	-	-	-	-
Fluoride	-	-	-	-	-	-	2	0.31	-	-	-	-	-
Hardness, as $CaCO_3$	-	-	890-7,600	523	-	7,830	2,200	540	5,500	-	0-22,800	-	-
Iron	246	-	7-220	-	-	5,500	6.3	0.6	1,640	-	0-2,820	0.5-2,200	440
Lead	-	-	-	-	-	-	-	-	-	-	<0.1-2.0	-	-
Magnesium	182	-	64-410	-	-	-	-	-	-	-	17-15,600	35-1,140	210
Manganese	-	-	-	-	-	1.66	0.06	0.06	-	-	0.09-125	-	-
Nickel	-	-	-	-	-	-	-	-	0.8	-	-	-	-
Nitrate N	-	-	-	-	-	1.70	0.70	1.60	-	-	-	-	-
Nitrite-N + Nitrate-N	-	-	-	-	-	-	-	-	-	-	0.2-10.29	0.4-10.29	1.5
Nitrogen, Total	-	-	-	-	-	-	-	-	-	2,000-10,000	-	-	-
Organic N	-	-	2-465	7	200	-	-	-	482	-	-	-	-
pH	-	5.7-8.4	6.0-6.5	-	-	-	6.3	7.0	-	-	3.7-8.5	5.09-7.25	5.98
Phosphates, P	-	-	0.1-10	-	-	2	0.4	3.0	43	-	6.5-85	0.25-85	3.2
Phosphorus, Total, P	-	-	-	-	-	-	-	-	-	-	0-130	0.5-98	9
Potassium	-	-	28-1,700	-	-	-	-	-	-	-	28-3,774	35-2,300	380
Sodium	-	-	85-1,700	-	-	900	810	74	3,800	-	0-7,700	44-1,588	280
Specific Conductance	-	-	-	-	-	-	-	-	-	-	2,810-16,800	978-16,800	4,970
Sulfate	-	-	84-730	3	1,950	680	2	2	375	-	1-1,558	7.4-1,558	90
Sulfide	-	-	-	10	-	-	-	-	-	-	-	-	-
Suspended Solids	1,000-2,500	-	-	-	-	-	-	-	26,500	-	10-700	8.9-923	197
Total Dissolved Solids	-	-	-	-	-	19,144	6,734	1,198	-	-	584-44,900	-	-
Total Solids	-	-	-	-	-	-	-	-	43,000	-	0-59,280	911-55,348	6,080
Zinc	-	-	-	-	-	-	0.13	0.10	129	-	0-370	-	-
Reference No.	2	3	4	5	6		9		10	11		16	

*STEINER, R.L. Chemical and Hydraulic Characteristics of Milled Refuse. Ph.D. Thesis. Drexel University, Philadelphia, Pennsylvania. 1973.

CHIAN, E.S.K. and F.B. DeWalle. Sanitary Landfill Leachates and Their Treatment. Proceedings ASCE, Journal of the Environmental Engineering Division 102, EE2, 411-31. 1976.

+All units are mg per liter except pH (pH units) and specific conductance (μmho/cm).

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Table 3

EFFECT OF SOLID WASTE DISPOSAL ON GROUNDWATER QUALITY
GROUNDWATER QUALITY BEFORE AND AFTER INTRODUCTION
OF "WET TIPPED" LANDFILL - 1961*

Measured Quantity	Concentration (mg/l) Upstream of Landfill	Concentration (mg/l) Downstream of Landfill
Total solids (residue)	450	5,000
Chloride	30	500
Alkalinity, as $CaCO_3$	180	800
Sulfate	120	1,300
Biochemical oxygen demand (BOD_5)	0	2,500
Organic nitrogen	0	70

*MINISTRY OF HOUSING AND LOCAL GOVERNMENT. Pollution of Water by Tipped Refuse. Her Majesty's Stationery Office, London. 1961.

Table 4

EFFECT OF LANDFILL DEPTH ON LEACHATE COMPOSITION AND POLLUTANT REMOVAL AT THE UNIVERSITY OF WEST VIRGINIA - 1965*

Parameter	Concentration (mg/liter)			Pollutant Removal (kg per cu m)		
	0.76 m Fill	1.98 m Fill	3.1 m Fill	0.76 m Fill	1.98 m Fill	3.1 m Fill
Alkalinity, as $CaCO_3$	10,630	16,200	20,850	--	--	--
Bicarbonate	--	--	--	9.4	7.1	5.9
BOD_5	14,760	26,200	33,360	12.7	10.6	9.0
Chloride	951	2,000	2,310	0.8	0.6	0.6
Hardness, as $CaCO_3$	7,600	13,100	10,950	2.8	1.8	1.1
Nitrogen, Total	613	1,389	2,508	0.6	0.6	0.6
Sodium and Potassium	1,634	3,963	5,109	22.0	16.6	14.4
Solids, Total	21,140	49,800	59,000	--	--	--
Sulfate	--	--	--	0.5	0.3	0.2

*QASIM, S.R. Chemical Characteristics of Seepage Water from Simulated Landfills. Ph.D. Dissertation. West Virginia University, Morgantown. 1975.

refuse. Approximately 102 cm of precipitation was artificially added to the cylinders over a period of 6 months and leachate samples were collected. The maximum concentrations of certain organic and inorganic components in the leachate from the three cylinders are presented in Table 4. Table 4 also presents the total weight removed per cubic meter from each depth of fill by 102 cm of simulated infiltration.

A summary of results presented by Qasim demonstrates the effect of depth on leachates generated by landfills. Concentrations of various pollutants were higher in leachates obtained from deeper fills. Concentrations of various pollutants per unit depth of fill decrease with increasing depths of refuse. For an equal amount of influent, shallower fills showed greater extraction rate per unit volume of fill than deeper fills. The bulk of the pollution was attributed to initial leaching.

Anderson and Dornbush[8] conducted an extensive investigation of the groundwater leaving a landfill in Brookings, South Dakota in 1967. An abandoned gravel pit of 160 acres with its base well below the water table was filled with municipal solid waste. The purpose of the investigation was to determine which chemical parameters were the most reliable indicators of the influence of landfills on the groundwater. Groundwater samples from 22 wells located over the site were analyzed for chloride, total hardness, alkalinity, sodium, pH, potassium, iron, nitrate, and specific conductance. A considerable increase in all constituents measured was observed in three wells immediately downstream of the fill area. Although the authors did not evaluate the potential pollution of municipal refuse, they did report an increase of up to 50 times the chloride content of native waters in the groundwater affected by the leachate. The major conclusion of this investigation was that two of the most important indicators of pollution from landfills are chlorides and specific conductance or total dissolved solids. Chloride ions are easily detectable, not readily absorbed by soils, not affected by biological processes, and apparently an abundant product of leachates.

Disposal sites in northern Illinois were investigated in 1970 by Hughes, et al.[9] Leachate samples from three landfills of varying age were obtained as near to the base of the refuse layer as possible. The results of these analyses are presented in Table 2 (Columns 6-8) Although no information is given in the study as to the composition of the solid waste in each fill, and the analyses were performed on only one sample, the results do show a decreasing trend with time. However, it was noted that refuse more than 15 years of age can still have a high total dissolved solids content - indicating that the stabilization of landfills is a long process.

The laboratory simulated landfill or lysimeter study conducted at Drexel University from 1967 to 1972 is the only study reported that was conducted under completely controlled laboratory conditions. It was also the only study reported in which the environmental conditions completely simulate the existing climatic conditions of a region, in this

case, southeastern Pennsylvania. The refuse was placed at as received moisture content and allowed to reach field capacity naturally through the addition of amounts of distilled water equal to the precipitation of the area minus the evapotranspiration. This infiltration was added on a weekly basis and varied from a rate of 8.9 cm per month during the wet periods to zero during the dry or summer periods. Approximately one year was required for the refuse to reach field capacity, but small quantities of leachate were generated before field capacity was reached. The maximum concentrations obtained in the first year are given in Table 2, column 9[10].

It was concluded that this initial leachate production came from the following sources: (1) From the refuse. Most of the initially generated leachate is squeezed from the organic components of the refuse by the compaction and placement procedure. (2) From channeling. Some of the water added at the top of the lysimeter may find a direct route through the refuse to the collection trough, due to any inhomogeneities in the refuse. (3) From an advanced wetting front. The wetting front in the refuse probably moves as a broad band rather than as a single line interface. As a result, substantial increases in leachate will occur before the entire system is at field capacity. (4) From the main wetting front. This is the leachate which is produced when the system reaches field capacity. At this time, the input water and the output leachate quantities become approximately equal.

Other studies have mentioned the leachate problem of refuse disposal in papers dealing with other aspects of the solid waste problem. Leo Weaver has stated that municipal refuse can generate leachates high in organic pollutants.[11] Data from this study are included in Table 2 (column 10).

Engineering Science in a study conducted in 1967 in southern California concluded that groundwater pollution, which may arise from refuse leachate reaching a water source, will be shown largely as an increase in total dissolved solids and specific conductance.[12]

Walker in 1969 found that a sand and gravel aquifer in Illinois was ineffective in removing dissolved chemical ions generated by a landfill.[13] He did report that travel of leachate through a short distance (3 to 5 m) of this aquifer will remove organic pollutants generated by landfills in Illinois and concluded by stating that inorganic pollutants constitute the greatest source of concern.

Roessler noted an increase in inorganic pollutants in an industrial water supply 2½ miles downstream from a refuse dump 10 years after the dump had started operation.[14] Lang noted that a dump containing primarily garbage polluted wells approximately 2,000 feet downstream.[15] He observed increases in inorganic pollutants such as total dissolved solids, hardness and chloride, and concluded that refuse dumps can cause a 100% increase in the inorganic pollutants in wells up to 2,000 feet away.

Table 2 (columns 11-13) presents a summary of values of raw leachate composition as compiled by Chian and DeWalle.[16] The ranges represent leachates examined by a number of investigators (Range 1-Column 11) and a variety of leachates studies at the University of Illinois (Range 2-Column 12). These data are the results of a recently completed literature review.

The conclusion to be drawn from this review of landfill leachate quality (as summarized in Table 2) is that its composition is highly variable from site to site. In addition, the data show that even at a given landfill, considerable variation is encountered with respect to both space and age. That is, variability is a factor within a landfill and also over the history of the site. Consequently, it is concluded that landfill leachate quality cannot be predicted a priori; and that this quality is even variable at a given site.

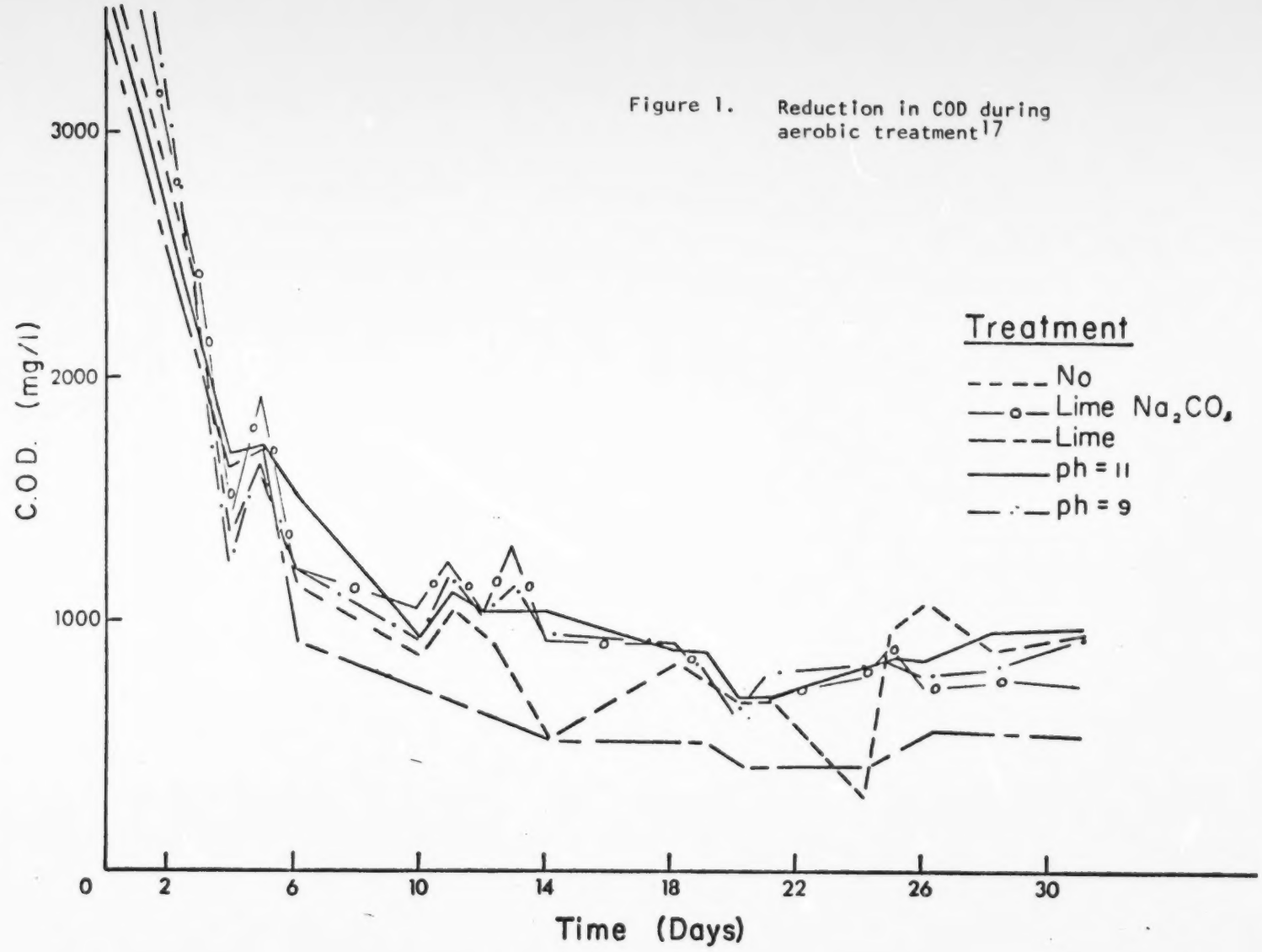
LEACHATE TREATMENT

Leachate treatment systems have been evaluated on a laboratory-scale at Drexel University. In one study[17], the purpose was to characterize the biodegradation of organic matter both with and without the supplementary addition of chemicals. The system consisted of five aerobic units which were treated in the following manner: (1) control-no treatment; (2) addition of sodium hydroxide to pH 9; (3) addition of sodium hydroxide to pH 11; (4) addition of lime; and (5) addition of lime plus sodium carbonate. Otherwise, all units were handled in the same manner. This procedure included preparation of an activated sludge culture by aerating leachate. Each experimental unit was seeded with this culture and was aerated at a rate of 94 liters of air per gram COD (1500 cu ft per lb COD). During the testing, all settled solids were recycled to the aeration tank with no sludge wastage. The aeration treatment systems were operated on a continuous basis with a hydraulic residence time of five days.

The COD values decrease quite rapidly during the first six days and thereafter approach a limit. The results indicate that there are components of leachate which are not amenable to treatment in an aerobic system. The time of adaptation of microorganisms for treatment of the organic fraction of leachate may be considerably longer than normal sewage. Volatile solids concentrations in these tests were low when compared to normal activated sludge systems. This may be one reason for the long time required for stabilization.

Figure 2 shows the high variation in the concentration of total dissolved solids in the treated effluent. The cyclic variation of

Figure 1. Reduction in COD during aerobic treatment[17]



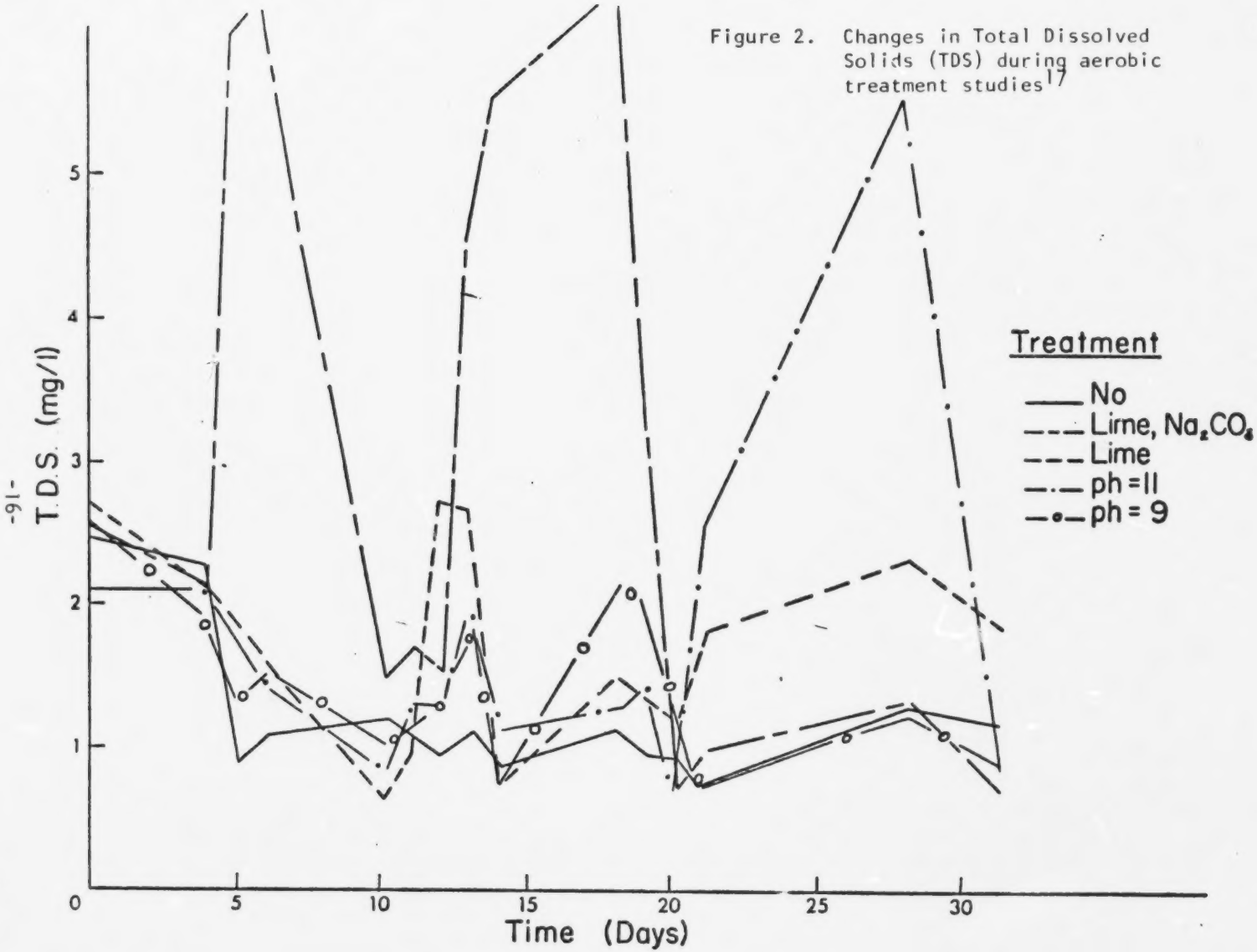


Figure 2. Changes in Total Dissolved Solids (TDS) during aerobic treatment studies[17]

several systems is of interest, but not all of the systems show this phenomenon. Since the withdrawal and addition of leachate was constant, there was no reason for the cyclic effect. Only pretreatment with lime gave any type of stability and COD reduction.

Thus, neither biological waste treatment nor chemical-physical treatment separately is able to reduce the BOD more than eighty percent. In fact, the efficiency of the chemical-physical process is considerably below this level. It is hypothesized that two reasons exist for the poor removal efficiency of each individual system: 1) the large percentage of high molecular weight organic materials, and 2) the biological inhibition caused by heavy metal presence. The physical-chemical treatment is needed to remove the metals and also to hydrolyze some of the organics, and biological treatment to stabilize the degradable organic matter.

In addition, biological treatment alone does not remove significant amounts of the heavy metals. In fact, biological units may be inhibited due to the toxic effects of the metals. Consequently, chemical and/or physical processing is needed for the removal of substantial amounts of these materials. Lime treatment is particularly effective in that it creates the alkaline conditions under which the metals become insoluble.

The removal of heavy metals during lime precipitation depends upon the formation of insoluble metal compounds, primarily hydroxides, at alkaline pH. The optimum set of conditions is not identical for all metals, and the result is that it is impossible to achieve the maximum theoretical removals for each metal within a single tank. In general, the optimum pH levels are in the range of 7-10.3[18] (see Table 5). Hexavalent chromium is not removed by lime addition unless it has previously been reduced to trivalent chromium.

These studies demonstrated that the aerobic treatment of sanitary landfill leachate is feasible and that pretreatment may be required. Lime precipitation appears to be the most favorable pretreatment method. The organic fraction of leachate was found to contain substances not readily assimilated by the microorganisms, and it was hypothesized that chemical treatment is needed to remove these organics.

Chian and DeWalle have recently completed an extensive review of leachate treatment techniques.[16] Their conclusion was that leachate collected from recently leaching landfills is best treated biologically. This is because the organic fraction of such leachate is composed predominantly of free volatile fatty acids which are readily biodegradable by either aerobic or anaerobic means. On the other hand, leachate from older landfills is more efficiently handled by chemical-physical processes, because these organics are more resistant to biodegradation. They also concluded that activated carbon and reverse osmosis were the most efficient chemical-physical methods in terms of the removal of organics.

Table 5

THEORETICAL REMOVAL OF HEAVY METALS DURING LIME PRECIPITATION*

Metal	Optimum pH	Theoretical Effluent Concentration, mg/l
Cadmium	10	1.0
Hexavalent chromium	--	--
Trivalent chromium	8.5-9.5	<1
Copper	9.0-10.3	0.01
Soluble iron	7	--
Lead	--	<0.1
Nickel	10	0.01
Zinc	--	<0.1

*PATTERSON, J.W. and R.A. Minear. Wastewater Treatment Technology. Prepared for Illinois Institute of Environmental Quality. 279 pp. Published by NTIS, Springfield, Va. PB 204 521. 1971.

The compilation of data presented by Chian and DeWalle indicate the following range of COD removal efficiencies for various treatment methods: 0 to 98 percent for aerobic biological; 87 to 99 percent for anaerobic biological; 17 to 40 percent for aerobic/anaerobic biological; 0 to 40 percent for chemical precipitation with alum, ferric chloride, ferrosulfate or lime; 34 to 94 percent for activated carbon and ion-exchange; 0 to 48 percent for chemical oxidation; 56-98 percent for reverse osmosis.[16]

As a means to bring order to the wide disagreement found, in the literature, Chian and DeWalle postulated the age of the landfill affected the character of the leachate, and that this character is best measured in terms of the ratios of chemical oxygen demand to total organic carbon (COD/TOC) or of biochemical oxygen demand to chemical oxygen demand (BOD/COD) (Table 6)[16].

SUMMARY

The state-of-the-art concerning the composition and treatment of sanitary landfill leachates has been assessed. The most obvious characteristics of leachate are its strength and its variability. Leachate is generally of much greater strength than domestic sewage. This is especially true in terms of organic materials and the potentially toxic heavy metals. As important a characteristic as strength is the variability of leachate composition. Leachate quality not only fluctuates from landfill site to site, but also from time to time at one landfill. Changes over time result from differences in seasonal hydrology and microbiological activity. Rainy weather may dilute the leachate, but, at the same time, may flush out large quantities of pollutional material. The typical pattern observed over many years is that the pollution potential of leachate is greatest during the first five years or so after placement, but that leachate strength remains significant for as long as ten to twenty years. This sequence is encountered because the microbiological processes responsible for the decomposing of the solid wastes are relatively slow acting and are first directed at the most readily biodegradable components of the waste.

Considerable differences are encountered in leachate quality when comparing landfills. In addition to the seasonal, hydrologic and age of landfill factors mentioned above, there are several other reasons for this observation. The chemical nature of the wastes accepted at the landfill has a marked effect on the composition of the leachate. The land disposal of industrial liquid and solid wastes is critical in this light.

The variability and the strength of leachate have important waste treatment implications. First, the sheer magnitude of the measures of pollution potential dictate the use of thorough waste treatment. Second, the changes encountered from landfill to landfill are such that waste

Table 6

LEACHATE TREATABILITY AS HYPOTHESIZED BY CHIAN AND DeWALLE*

Leachate Quality				Treatment Efficiency+						
$\frac{COD}{TOC}$	$\frac{BOD}{COD}$	Age of Fill	COD, mg/l	Biological	Chemical Precipitation	Chemical Oxidation	Ozonation	Reverse Osmosis	Activated Carbon	Ion Exchange
>2.8	>0.5	Young (<5 yr)	>10,000	G		P	P	F	P	P
2.0-2.8	0.1-0.5	Medium (5 yr-10 yr)	500-10,000	F	F	F	F	G	F	F
<2.0	<0.1	Old (>10 yr)	<500	P	P	F	F	G	G	F

*CHIAN, E.S.K. and F.B. DeWALLE. Sanitary Landfill Leachates and their treatment. Proceeding ASCE, Journal of the Environmental Engineering Division 102, EE2, 411-31. 1976.

+(G = good; F = fair; P = poor)

treatment techniques applicable at one site are not necessarily directly transferable to other locations. That is, it may be mandatory that each instance be separately engineered to achieve adequate treatment. Third, the fluctuations in leachate quality which occur over both short and long time intervals must be accounted for in the treatment design. Not only must processes be designed to efficiently treat the waste flow from minute to minute, but the design must also reconcile the possibility that treatment techniques which work well for a young leachate may become wholly inadequate as landfill age increases.

It is apparent today that most landfill leachate cannot be treated adequately by just conventional chemical/physical treatment or conventional biological treatment. Rather, what is needed is a combination of the two approaches with perhaps a supplementary form of advanced wastewater treatment. The purpose of this project is to investigate, at both the full and bench-scale levels of operation, the efficiency of treatment afforded by these processes.

III. LEACHATE TREATMENT SYSTEM

The leachate treatment facility being used in this study is located at the GROWS Landfill in Tullytown, Falls Township, Bucks County, Pennsylvania (see Figure 3). The plant is designed to provide maximum operational flexibility in order to permit full-scale testing of a variety of treatment sequences. Plant design and treatment modes are considered in subsequent paragraphs.

The sanitary landfill has a surface area of 50 acres. The landfill will be filled with about 1,400,000 cu m of refuse over the next several years. The time required to fill the landfill depends upon many unknown factors, but it is estimated that it will probably be between five and ten years. The receipt of refuse is about 800 tons per day. Eighty-five percent of the refuse is from municipal sources. The remainder is industrial and commercial. The landfill is also permitted to accept sewage sludge and selected industrial liquid wastes.

The landfill is located in the semi-humid northeastern part of the United States. The ninety-eight year monthly average precipitation and temperature data are given in Table 7. In this region there is a net positive infiltration of rainfall into the landfill. As long as there is a net positive infiltration, leachate will eventually begin to be produced by the landfill.

Because of these meteorological conditions and the site hydrologic situation, groundwater pollution potential existed. To alleviate this pollution potential the Pennsylvania Department of Environmental Resources required the landfill to be underlain by an impervious asphaltic membrane. This membrane system was designed to collect and transport the leachate to the leachate treatment plant.

The treated effluent is discharged to the Delaware estuary. The river zone is tidal and flow figures are not available. At the nearest gage (Trenton) the drainage area is 6700 square miles and the projected low flow is 33,000 liters per second. The discharge of treated effluent directly to the Delaware River occurs only during the months of December through April. During the remainder of the year, the effluent is returned to the landfill. The landfill has ample storage capacity in the pore space so that storage for six months does not create any difficulties. The effluent is spread on the landfill using aeration nozzles.

The treatment plant operates under permits from the Commonwealth of Pennsylvania Department of Environmental Resources Water Quality Section and the Delaware River Basin Commission. The effluent criteria for the facility are summarized in Table 8.

Table 7

Precipitation and Average Monthly Temperature Data
Trenton, New Jersey*

Month	Rainfall		Temperature	
	cm	in.	°C	°F
January	8.87	3.10	0.8	33.4
February	6.58	2.59	1.0	33.8
March	9.75	3.84	5.1	41.3
April	8.15	3.21	11.1	52.1
May	9.19	3.62	16.9	62.7
June	9.14	3.60	21.7	71.4
July	10.62	4.18	24.2	76.0
August	12.12	4.77	23.3	74.3
September	8.89	3.50	19.6	67.6
October	7.21	2.84	13.5	56.5
November	8.03	3.16	12.7	45.1
December	7.29	2.87	1.7	35.1
Total	104.85	41.28		

* Trenton, N.J. Weather Bureau, 30 Year Average.

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Figure 3. Location of Leachate Treatment Plant

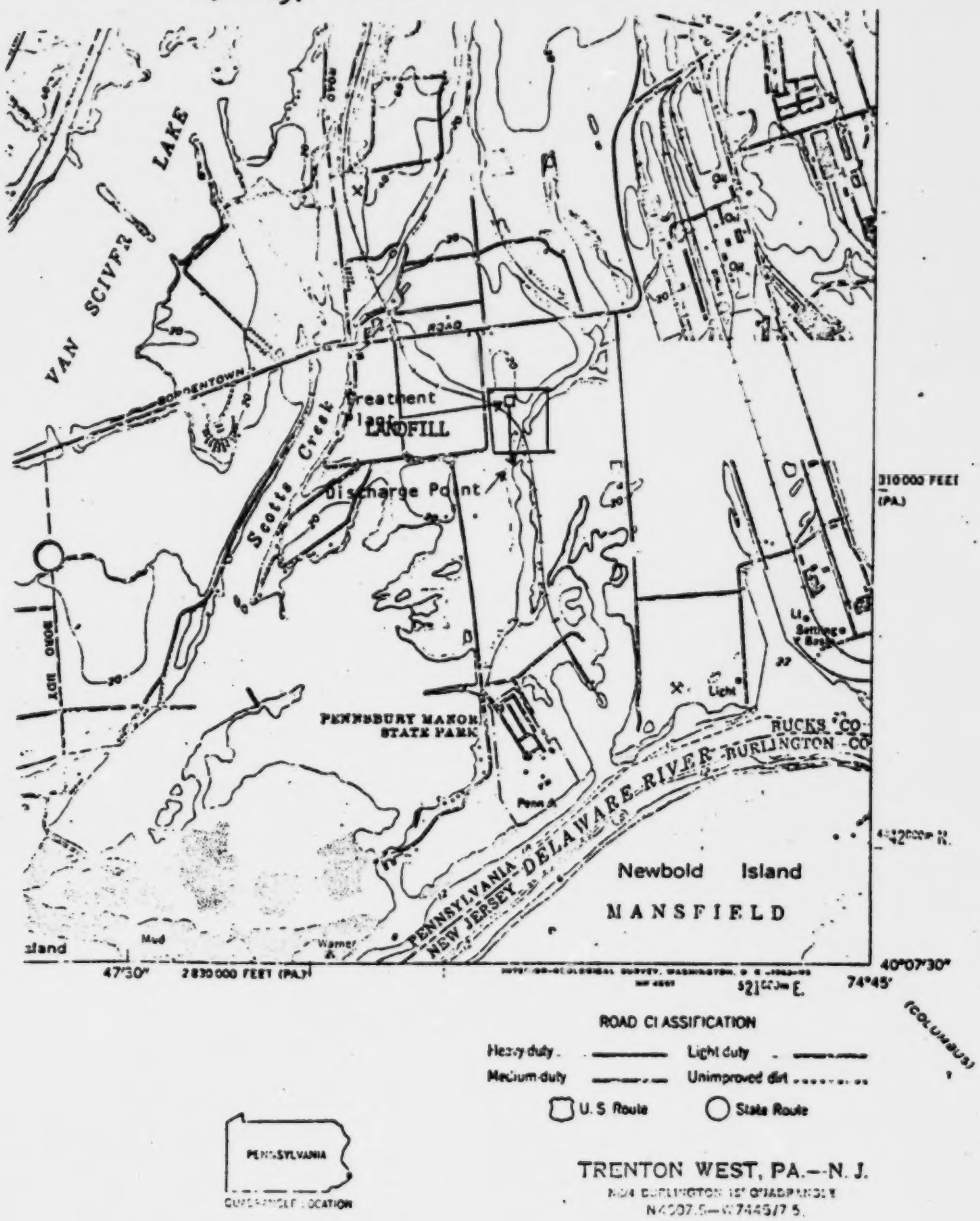


Table 8

SUMMARY OF EFFLUENT CRITERIA* FOR
GROWS SANITARY LANDFILL LEACHATE TREATMENT FACILITY

Parameter	Maximum Concentration mg/liter
BOD	100.0
Ammonia-Nitrogen	35.0
Phosphate	20.0
Oil and grease	10.0
Iron	7.0
Zinc	0.6
Copper	0.2
Cadmium	0.02
Lead	0.1
Mercury	0.01
Chromium	0.1

*Commonwealth of Pennsylvania Department of Environmental Resources and Delaware River Basin Commission.

Design Overview

The purpose of this section is to briefly summarize the design criteria and to discuss the design itself of the treatment facility. The effluent limits have been mentioned above and presented in Table 8. The following paragraphs are devoted to a discussion of the leachate quantity and quality as estimated for design purposes.

Design Flow

The source of liquid waste is the leachate which results from the degradation of refuse and percolation of rain water through the landfill. In addition, as the treated effluent is recycled to the landfill during the summer months, and to the Delaware River during the winter, the raw leachate volume includes this recycled effluent. The quantity of waste which is generated is dependent upon many individual factors of the landfill. The maximum generation of waste (includint the recycled volume) for design purposes was estimated to be about 20 liters per sq m-week at this site. However, the production of leachate is dependent upon the time cycle, both as to placement and to the season of the year. Leachate itself occurs as the result of the excess of infiltration over evapotranspiration and the soil moisture deficit. Thus, the actual generation of leachate depends upon precipitation patterns, landfill moisture and effluent recycling.

Since the generation of leachate is a function of the age of the fill, not all the expected leachate will be produced simultaneously. There is an initial period of operation when the landfill comes to field capacity, followed by an extended period of leaching of contaminants, after which there exists a state of degradation when the leachate is no longer of a polluting nature. It is possible that some portions of the landfill will be in this latter state when the final parts of the landfill are being completed. Hence, the maximum flow of 20 liters per sq m-week is a value which may never be attained for extremely strong leachate. This maximum flow rate was determined using the site meteorological data presented in Table 7 and the procedure developed by Remson, Fungaroli and Lawrence[1].

Design Leachate Characteristics

The leachate strength parameters used for design purposes are presented in Table 9. These were obtained through a modest sampling program conducted during the very early stages of the landfill. However, as discussed in Chapter II, the exact character of waste is difficult to predict for a number of reasons, including the fact that it is subject to dilution when the infiltration is high. In addition, because of the on-site variability, it is possible that single samples do not accurately reflect the character of the waste.

Table 9

DESIGN LEACHATE CHARACTERISTICS

Constituents	Raw Leachate*
BOD	1500
Suspended Solids	1500
Total Solids	3000
Percent Volatile	55
pH, pH units	5.5
Chlorine	200
Iron, total	600
Zinc	10
Chloride	800
Organic Nitrogen	100
Nitrate	20
Sulfate	300
Copper	1
Hardness	800
Alkalinity	1100
Color, standard units	50
Flow, mgd	.144
Temperature, ^{o}F	80

*All units are mg/l except pH, color, flow, and temperature.

Design Concept

As discussed in Chapter II, a combination of chemical/physical treatment plus biological treatment is often required for leachate treatment. The principle is that the chemical/physical units can be used for the removal of refractory organics and for pretreatment prior to the biological process. In the latter case, the chemical/physical processes are used for the removal of potentially inhibitory materials such as heavy metals and ammonia-nitrogen. The function of the biological units is the stabilization of organic matter and the oxidation of ammonia nitrogen. As a result of the findings discussed in Chapter II and the design leachate quality, this treatment plant was designed to consist of lime treatment and sedimentation followed by activated sludge and chlorination. Air stripping of ammonia and nutrient addition are included in the chemical/physical section. A schematic of the leachate treatment plant appears as Figure 4.

Leachate Collection System. The raw leachate is contained within the lined landfill which was designed to allow for the collection by gravity of leachate at three locations. These locations are outfitted with manholes from which the leachate is pumped and transported via pressure lines to the treatment facility. The leachate enters the plant via a one thousand gallon holding tank in which little mixing occurs because the flow from the individual manholes is highly variable, and pumped sequentially.

Chemical/Physical Section

The chemical/physical portion of the plant consists of the following: chemical precipitation and coagulation, sedimentation of precipitate, air stripping at elevated pH for ammonia removal, neutralization and nutrient supplementation. Each of these are discussed in the following paragraphs.

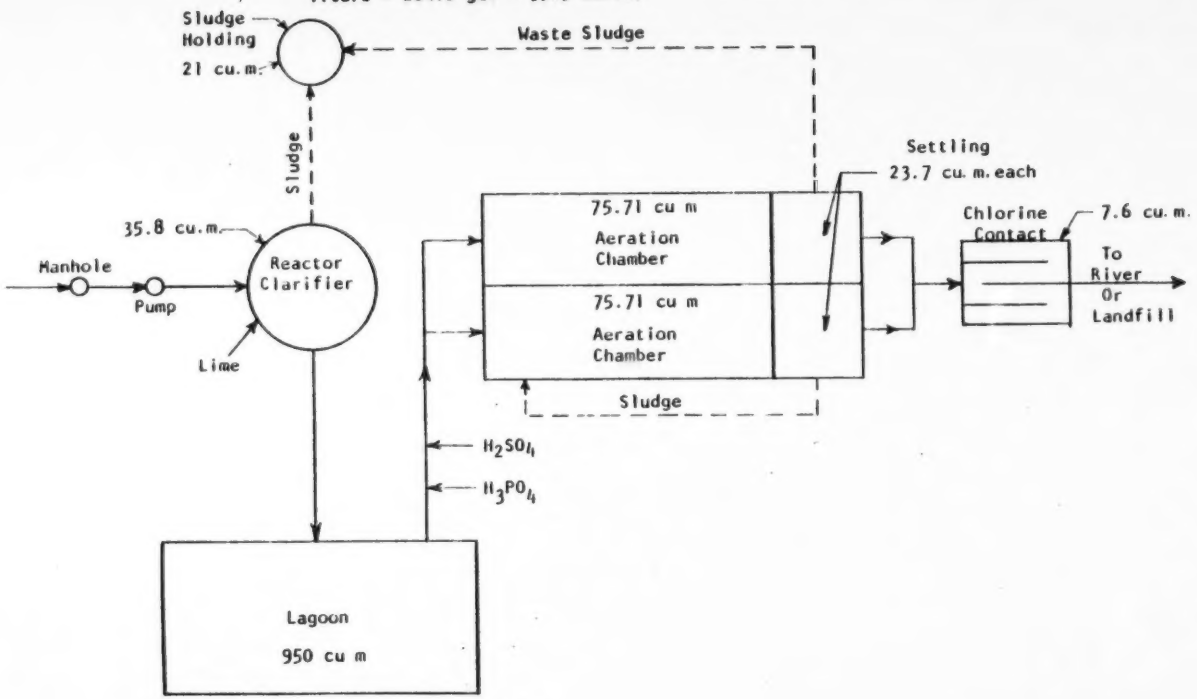
Chemical Precipitation. In the chemical treatment phase, the major design goal was the removal of inorganic materials. In particular, metals that may interfere with the subsequent biological treatment process are removed; also, the metals are removed to achieve discharge standards (Table 8). As part of the chemical treatment, the biochemical oxygen demand will also be reduced, but the design percentage of reduction was 30 to 50 percent, on the basis of the experience with municipal wastewater and with leachate as discussed in Chapter II.

The chemical treatment step consists of flash mixing followed by quiescent conditions favorable for coagulation as well as sedimentation of the chemical sludge. Lime has been the only chemical utilized in this chemical precipitation step. However, additional feeders and points of injection have been provided for the use of other chemicals if necessary. Other chemicals which might be used include alum, ferric chloride, synthetic polymers, and powdered activated carbon.

This unit is an upflow solids contact reactor clarifier. Lime slurry is added to cause coagulation and precipitation of the waste

Figure 4

SCHEMATIC FLOW SYSTEM #1 WITH AMMONIA STRIPPING LAGOON
Unit volumes are shown in cubic meters (1 cu m = 1000 liters = 264.2 gal = 35.3 cu. ft)



materials. The lime is pumped at a rate commensurate with the rate of leachate production. The lime slurry is flash mixed with the incoming waste, and mixing, flocculation and upflow clarification occur within a single unit. Solids contact is optimized by variable sludge recycle. The chemical treatment facility is a 3.66 m diameter, 3.66 m deep cylinder with a hydraulic retention time of 1.7 hours at 380 liter/min flow rate.

Sludge is drawn off the bottom of the reactor clarifier and placed in a common sludge holding tank with the waste activated sludge. Sludge return pumps are available to recirculate the sludge and mix it with the incoming waste water to reduce the amount of chemicals which are needed for precipitation. (However, the practice to date has been to use lime and to not recirculate the sludge.). The amount of sludge that is produced in this step depends upon the composition of the leachate. The design projection was that approximately 5 percent of the flow will be produced in sludge at 1 percent solids concentration.

Air Stripping of Ammonia. As a means of controlling excessive levels of ammonia in the lime treated stream and in the final effluent, a lagoon incorporating air stripping of ammonia is included in the chemical/physical section of the plant. The lagoon is located after the chemical-precipitation-clarification unit in order to take advantage of the high pH of the upflow solids contact reactor clarifier effluent and to minimize the solids loading on the lagoon.

The volume of the lagoon is 950 cu m, thus providing a detention time of approximately 1.74 days at design flow. The primary function of the lagoon is to encourage air stripping of ammonia by an elevated influent pH of 10, aeration and high internal recycle with splash plate to increase the air/water interface. The lagoon is lined with chlorinated polyethylene. In addition to ammonia removal, the lagoon provides equalization in terms of both flow and sanitary parameters.

Neutralization and Nutrient Supplementation. Sulfuric and phosphoric acids are added to reduce the pH of the leachate prior to entering the biological waste portion of the process. Phosphoric acid replenishes the supply of o-phosphate, a necessary biological nutrient, which is precipitated and removed following the addition of lime.

Biological Treatment Section

The biological treatment units consist of two aeration and two secondary clarifiers. The units may be operated in series or parallel. The capacity of each tank is 75,710 liter, which corresponds to a 6.6 hour detention time at the maximum flow rate of 380 liter/min. The aeration chambers are provided with diffused aerators, each driven by a 14.2 cu m per min blower.

Depending on the actual hydraulic residence time in the aeration tanks, the activated sludge units were designed to operate in either the conventional or extended aeration modes. In order to achieve this, the mixed liquor volatile suspended solids (MLVSS) would be maintained in the range of 3000-8000 mg/liter. This level is high relative to that normally maintained in units handling municipal wastewater. However, it is necessary because of the high BOD loading, and because of the requirement to remove about 90 percent of the BOD remaining after chemical/physical treatment. The MLVSS is maintained by return sludge pumps capable of delivering a return sludge flow equal to 200 percent of the influent flow.

The waste sludge from the activated sludge units and from the chemical treatment process are stored in the sludge holding tank. The capacity of this tank is 21 cu m, and sludge is removed as required and conveyed back to the landfill via tank truck.

Separation of treated wastewater from the MLVSS is achieved by gravity sedimentation in the secondary clarifiers. The total clarifier volume is 47,318 liter, in two parallel independently operable units. Sludge return is provided with air lifts installed in the final settling tank. A skimming device is located in the settling basin in front of the scum baffle to remove floating material which will be returned to the aeration compartment. The maximum surface overflow rate is 20.4 cu m per day per sq m (500 gpd/sq.ft.) based on the peak flow of 380 liter/min.

Final effluent is directed to the chlorine contact tank after secondary clarification. The chlorine contact tank provides a retention time of 20 minutes at the 380 liter/min flow rate. The effluent after chlorination is discharged to the Delaware River or to the landfill depending upon the season of the year. The chlorine contact tank is a simple baffled tank to assure mixing of the chlorine which is provided by hypochlorination.

IV. MATERIALS AND METHODS

Experimental Systems

The leachate treatment plant, although designed for chemical/physical treatment followed by biological treatment, was equipped with sufficient flexibility to provide for operational evaluation of a variety of treatment sequences. These sequences are each defined in the following paragraphs with reference to Figure 4.

System 1 - Chemical/Physical followed by Biological Treatment

System 1 is the basic treatment sequence with lime treatment for metals removal followed by ammonia stripping and conventional activated sludge. System 1a refers to the use of System 1 when the air stripping was not used, whereas System 1b signifies that the lagoon was included in the flow sequence. System 1a was tested in the late winter and spring of 1976, and System 1b in the summer of 1976.

System 2 - Chemical/Physical Treatment

Two subsystems have been evaluated. These, Systems 2a and 2b, consist of lime treatment either with or without subsequent removal of ammonia by air stripping. The system without ammonia stripping (System 2a) was evaluated in the winter and spring of 1976; and System 2b in the summer of 1976.

System 3 - Biological followed by Chemical/Physical Treatment

This is the reversal of System 1. This system was studied during the winter of 1976. The results indicated poor treatment efficiency, most likely due to heavy metal and ammonia toxicity. However, it might be argued that a sufficient amount of activated sludge had not developed. Therefore, System 3 will be reevaluated in order to test this latter hypothesis.

System 4 - Biological Treatment

This system has been tested, the results showing poor treatment efficiency. However, as indicated above, the performance might improve if a previously acclimated activated sludge were available. Consequently, System 4 will be operated and tested simultaneously with System 3.

Process Monitoring

An analytical laboratory has been established in a trailer located immediately adjacent to the treatment plant. The trailer is outfitted with the apparatus indicated below and is environmentally controlled with a heating/air conditioning system. The need for extensive bench-

Table 10

ROUTINE LABORATORY CHEMICAL ANALYSIS

Item	Method	EPA Storet No.	Detection Limit
Daily			
pH			
Chemical oxygen demand	Dichromate reflux	00349	--
Dissolved oxygen	Electrode	00299	--
Mixed liquor suspended solids	Gooch crucible	70300	--
Mixed liquor settleable solids	Gooch crucible	50086	--
Dissolved solids	Gooch crucible	00530	--
Volatile suspended solids	Gooch crucible	00520	--
Total residue	Gooch crucible	00500	--
Weekly			
Alkalinity	Titrimetric (pH 4.5)	00410	--
Biochemical oxygen demand	Probe ethod	00310	--
Total hardness	Titrimetric	00900	--
Kjeldahl nitrogen	Titrimetric	00625	--
Ammonia nitrogen	Distillation	00610	--
Phosphate	Persulfate digestion	00665	--
Sulfate	Gravimetric	00945	--
Chloride	Titrimetric	00940	--
Total iron	AA*	--	0.02
Chromium	AA	--	0.02
Copper	AA	--	0.01
Cadmium	AA	--	0.002
Lead	AA	--	0.05
Mercury	Mercury analyzer	--	0.0002
Zinc	AA	--	0.005
Nickel	AA	--	0.005
Calcium	AA	--	0.003
Magnesium	AA	--	0.005
Sodium	AA	--	0.002
Potassium	AA	--	0.005
Aperiodic			
Oil & Grease	Hexane extraction		

*Atomic Absorption Spectroscopy

scale testing and the large number of analyses needed for process control and monitoring made the on-site laboratory mandatory. The laboratory is operated by the chemist-operator employed specifically for this project.

The chemical analyses performed routinely are presented in Table 10. These have been selected on the basis of four criteria: they represent the most common chemical parameters used in the literature to characterize landfill leachate; they provide sufficient data to completely evaluate the unit operations, process and total system efficiency; they are needed for process control; and they are required to specifically define the leachate.

All analyses are performed in accordance with Standard Methods 13th Ed. 1971; ASTM Standards pt-23, 1972 and EPA Methods, 1974 Ed.[19-21] The analyses are performed on total samples as opposed to filtrate samples. Some preparation of the raw leachate is required.

Electrometric techniques are used in the determination of dissolved oxygen (with periodic checks using the Azide Modification of the Winkler Iodometric procedure), pH, and dissolved solids. Atomic absorption spectroscopy is used for iron, chromium, copper, nickel, zinc, sodium, cadmium, lead, and potassium.

A number of sampling points are used in the analysis program. Routinely, samples are collected of (1) the raw leachate; (2) chemical/physical sedimentation tank effluent; (3) lagoon effluent; (4) mixed liquor; and (5) biological sedimentation tank effluent. In addition, samples are collected on an irregular basis from the three landfill manholes and directly from the individual treatment units. In all cases, every effort is made to ensure that a representative sample is obtained.

Bench-Scale Testing

As a supplement to the full-scale treatment processing, some smaller scale work has been undertaken. This effort serves two purposes. First, it allows the operator to readily develop operational guidelines. For example, jar tests have been used to determine proper chemical dosages.

The second purpose is to provide an opportunity for evaluating additional treatment techniques. Specifically, bench-scale testing has been used to evaluate activated carbon treatment of raw leachate. Granular activated carbon has been used in column studies to obtain performance characteristics. The results are discussed in Chapter 5. Additional carbon studies, as a final effluent polishing technique, will be undertaken in the coming months.

Statistical Tests

The following notation is used throughout: n, number of data points; $\bar{x}$, arithmetic means; and s, standard deviation. The mean is calculated as

$$\bar{x} = \frac{1}{n} \sum x_i$$

and the standard deviation as

$$s = \frac{\sum (\bar{x} - x_i)^2}{n-1}$$

where the x_i are the n data points,

and the coefficient of variation is

$$cv = \frac{s}{\bar{x}}$$

The value of the coefficient of variation decreases with decreasing variability.

V. RESULTS AND DISCUSSION

Preliminary Results

Raw Leachate Quality

A summary of actual leachate quality is shown in Table 11. These data are a summary of the entire set of results. As is evident from a comparison of Tables 9 and 11, there are significicant differences between the two. These changes toward increased leachate strength are seen mainly between the design and actual raw leachate organic matter, dissolved solids, pH and ammonia. The biodegradable organics concentration is three times the design level. Dissolved solids are an order of magnitude greater, caused by increased hardness, organic matter and chloride. The ammonia concentrations actually observed have been extremely high and have been a source of operating problems especially in the biological units. The factors influencing this difference between the projected and observed leachate quality have been discussed in Chapter II.

Considerable variability in the raw leachate quality has been noted on a day-to-day basis. The influent COD data are presented in Figure 5 to show this variability. An additional indication is provided by the coefficient of variation data provided in Table 14, columns 3 and 10.

Lime Dosage

Jar tests were carried out in the laboratory in order to determine proper dosages for the lime treatment unit. In the first series of tests, three types of lime were monitored for their ability to raise the pH of raw leachate to 10.0. The limes used were high magnesium lime, high calcium quick lime and high calcium hydrated lime. The results may be summarized as:

	Dosage	
	lb/1000 gal	kg/cu m
High Magnesium Lime	125	15
High Calcium Quick Lime	52	6.2
High Calcium Hydrated Lime	50	6.0

It is economically impractical to use the high magnesium because its properties are such that to raise the pH to 10.5 requires 30 kg per cu m (250 lb per 1000 gal).

Required dosages to obtain pH 10.0 are nearly identical for both types of high calcium lime. For pH greater than 10.0, the high calcium quick lime becomes more efficient and hence is desirable economically. However, the slaking characteristics of the quick lime have caused pro-

Table II

LANDFILL LEACHATE CHARACTERISTICS*

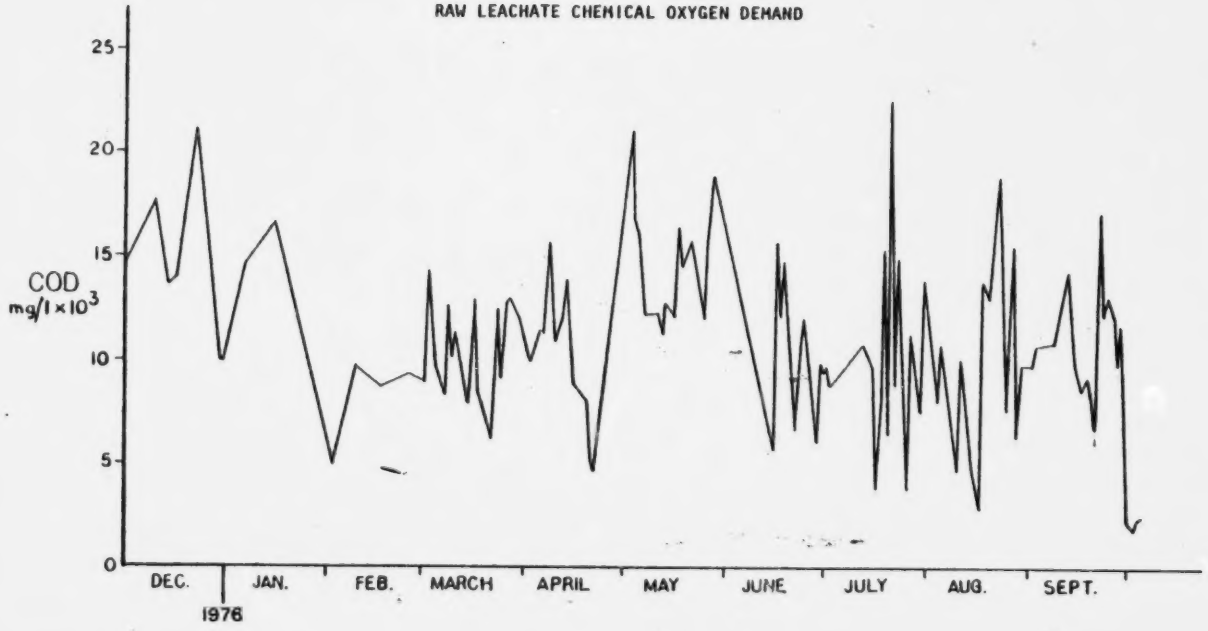
Item	Concentration+
Biochemical oxygen demand (5-day)	4,460
Chemical oxygen demand	11,210
Total solids	1,154
Suspended solids	1,994
Dissolved solids	11,190
pH, pH units	7.06
Alkalinity, as $CaCO_3$	5,685
Hardness, as $CaCO_3$	5,116
Calcium	651
Magnesium	652
Phosphate	2.81
Ammonia-N	1,966
Kjeldahl-N	1,660
Sulfate	114
Chloride	4,816
Sodium	1,177
Potassium	959
Cadmium	0.043
Chromium	0.158
Copper	0.441
Iron	245
Nickel	.531
Lead	.524
Zinc	8.70
Mercury	.0074

*These values represent the arithmetic mean of all raw leachate data.

+All units mg/liter unless otherwise noted.

FIGURE 5

RAW LEACHATE CHEMICAL OXYGEN DEMAND



blems with pumping the resultant slurry so that this lime cannot be used with the available lime feed system. On the other hand, the hydrated lime does not offer such problems, and consequently, the high calcium hydrated lime is being used.

Sulfuric Acid Dosage

The amount of sulfuric acid required to lower the clarifier effluent to 6.5 has been determined. To do this, approximately 0.6 ml of concentrated sulfuric acid per liter leachate (0.6 gal/1000 gal) is required. The actual dosages used are presented later in this chapter as part of treatment costs.

Phosphoric Acid Dosage

The need for a phosphoric acid supplement became apparent from three lines of evidence: (a) very low phosphate levels in the chemical/physical effluent; (b) unrealistically low values obtained in the biochemical oxygen demand test; and (c) poor biological treatment performance following the chemical/physical process. These points all indicate that the chemical/physical treatment effluent is phosphorus deficient, and that, if biological treatment is to follow, it must be supplemented with phosphorus. Additional evidence was collected by performing a series of BOD_5 tests in which a variable amount of phosphorus supplement was added to the bottles. It was observed that the BOD increased with the amount of phosphorus. In addition, bench scale tests indicated greater activated sludge production when o-phosphate was added. Thus, it has been concluded that orthophosphate, as phosphoric acid, should be added to form a nutrient supplement.

The preliminary calculation of phosphoric acid dosage has been made on the basis of providing a ratio of BOD:N:P of 100:5:1. This is approximately 15-23 liter (4-6 gal) phosphoric acid per day. More recently, however, the criterion is to add phosphoric acid so that there is measurable o-phosphate in the bio-unit effluent. This amounts to about 3.8 liter (1 gal) of phosphoric acid per day.

SYSTEM 1 - PHYSICAL/CHEMICAL PLUS ACTIVATED SLUDGE

System 1 consists of chemical/physical treatment followed by activated sludge. The early attempts (winter and spring 1976) to develop an activated sludge culture were not successful. As discussed in connection with Systems 3 and 4, phosphorus limitation and ammonia toxicity inhibited these efforts. These two difficulties were overcome by the addition of phosphoric acid as a neutralizing agent for the lime treatment effluent and by the use of air stripping of ammonia. System #1 was successful only after the implementation of these measures and, as a result, this discussion is limited to the time period after implementation.

The BOD, COD, and ammonia-N data showed a dramatic improvement in treatment efficiency during August. Approximately four weeks were needed to develop the activated sludge microorganisms to the point where they were capable of rapid growth at the expense of the leachate substrate. Table 12 shows the results following the successful adaptation of the activated sludge. The starting date for analysis of these data was chosen as August 1, 1976, which marks the point at which the activated sludge had become fully acclimated in terms of ammonia-N, BOD and COD removals.

The results presented in Table 12 demonstrate the high level of treatment efficiency attainable with System 1. This treatment system can achieve removals greater than ninety percent for ammonia, BOD, COD, and iron; and greater than two-thirds for suspended solids, alkalinity, magnesium, kjeldahl-N, cadmium, lead, mercury, and zinc. Relatively poor removals of chromium and nickel were achieved with System #1. Chromium removals have averaged 28.6 percent, and this low efficiency is attributed to two factors. In the first place, any hexavalent chromium will not be removed by lime precipitation without previous oxidation to the trivalent state; and, in the second place, the precipitation of trivalent chromium at pH 10 is not optimal (See Table 5). This is because the solubility of chromic hydroxide is at a minimum at pH 8.5-9.5 and increases with increasing pH. During the time period represented by Table 12, the clarifier pH was consistently above 10, and frequently over 11, whereas during the period represented by Tables 14 and 17 the pH was consistently below 10. Thus, we are able to see chromium removals as a function of clarifier pH, and this opens the possibility that the operator can control pH as a method of differentially affecting effluent heavy metals concentration. The fairly low removals of nickel may also be related to the relatively low hydrogen ion concentrations. Based on theoretical considerations of the solubility of nickel hydroxide, the nickel concentration in the effluent should be on the order of ρ.01 mg/l[18], as opposed to observed average of 0.27 mg/l. This observation is perhaps also due to the formation of nickel complexes with unknown chelating agents within the landfill.

The results observed with phosphates, sulfates and chloride should be noted. Little removal of chloride takes place because of its relative biochemical inertness. The concentration of phosphates and sulfates increase during the course of treatment because of the addition of sulfuric and phosphoric acids as neutralizing agents. Initially, both acids were used in excess in order to encourage the growth of the activated sludge microorganisms. That is, the goal was to provide a very favorable environment in terms of both pH and the nutrient phosphorus. However, following the successful acclimation of the activated sludge, the addition of sulfuric acid has stopped while that of the phosphoric acid has been drastically cut back. Neutralization is no longer needed because of the recarbonation effect of aeration in the lagoon. The present criterion for phosphoric acid addition is to provide just enough

Table 12

SYSTEM 1* TREATMENT PERFORMANCE AFTER ACCLIMATION OF ACTIVATED SLUDGE
(August 1976)

Item	Concentration		Percentage Removal
	Influent	Effluent	
Suspended solids	445	126	71.7
Dissolved solids	10849	5369	50.5
COD	9689	576	94.1
BOD	4993	60.5	98.8
Alkalinity	3718	388	89.6
Hardness	4647	1629	64.9
Magnesium	495	109	78.0
Calcium	819	472	42.4
Chloride	3172	2925	7.8
Sulfate	197	1333	--
Phosphate	1.62	17.8	--
Ammonia-N	510	46.5	90.9
Kjeldahl-N	539	141	73.8
Sodium	992	724	49.1
Potassium	823	505	38.6
Cadmium	0.049	0.014	71.4
Chromium	0.105	.075	28.6
Copper	.313	.078	75.1
Iron	205	.96	99.5
Nickel	.52	.27	48.1
Lead	.545	.12	78.0
Zinc	3.64	.44	87.9
Mercury	.015	.004	73.3

*This system consists of lime addition, sedimentation, air stripping, neutralization, nutrient supplementation and activated sludge.

to satisfy the microorganisms' demand as indicated by an effluent concentration of about 1 mg/l. That is, the criterion at present is to add enough H_3PO_4 so that there is residual phosphate (1 mg/liter) in the effluent. This level is one to two orders of magnitude greater than the amount in the lagoon.

The difficulties in obtaining a healthy culture of activated sludge have been overcome. The operating experience indicates that the earlier problems were in fact due to ammonia toxicity and phosphorus limitation. The ammonia stripping lagoon has maintained the concentration of this inhibitor below toxic levels. The mean and standard deviation of the lagoon effluent ammonia concentration are such that 99 percent of the time, the feed to the activated sludge unit is less than 425 mg NH_3-N/liter. The corresponding raw leachate concentration is 1285 mg NH_3-N/liter. Thus, the lagoon has functioned to minimize the shock loading effect of inhibitory ammonia concentrations. This in turn provided an opportunity for the development of microorganisms capable of extracting carbonaceous BOD. As this group became established, organic concentrations in the mixed liquor were reduced and this created conditions suitable for the development of nitrifying organisms. Growth of these groups of microorganisms has resulted in the low effluent concentrations of both BOD and ammonia.

As seen in Table 12, a considerable change in alkalinity occurs during biological treatment. There are two main mechanisms by which this occurs. First, the aeration causes some removal of gaseous carbon dioxide, resulting in a shift of the carbonate equilibria and a change in total carbonate alkalinity. It is probable, however, that in this case, nitrification has a more profound effect on alkalinity. As a result of nitrification, alkalinity is consumed and carbon dioxide is produced. Neglecting the effect of biomass synthesis, the theoretical value is 7.14 mg alkalinity as $CaCO_3$ destroyed per mg NH_4^+-N oxidized. In this study, a ratio of 5.6 mg alkalinity per mg NH_4^+-N removed has been observed since the development of the activated sludge culture. This is in excellent agreement with the theoretical value if one considers that the observed value includes the effects of biomass growth and air stripping in the bio-units as well as shifting chemical equilibria in addition to those of nitrification.

Operational Comments

Operating problems have been encountered in the biological treatment unit, and these are being addressed and solved at this time. The most serious of these has been a tendency of solids to float in the secondary clarifier. The result of this is a decreased ability to achieve the expected level of solids separation. The presence of the floating sludge has been investigated and is characterized as being the result of three separate and distinct causes: flotation, turbulence and denitrification. It is apparent that there is some carryover of floating materials to the clarifier from the aeration tank. The leachate contains considerable

amounts of surface active materials capable of flotation, and this contributes significantly to the carryover phenomenon. The scum control device is not capable of handling the unexpectedly large amount of these materials. At the same time, an excessive amount of turbulence exists in the secondary clarifier. These first two sources of the problem are being corrected by the installation of mechanical skimmers and construction of a baffle on the inlet side of the secondary clarifier.

The reduction in solids separation efficiency is compounded by a propensity of the activated sludge to become anaerobic and to rise in the clarifier due to denitrification. This is seen clearly when one follows closely the settleable solids test. At first, the sludge settles properly with a dense sludge layer overlain by a clear supernatant containing little turbidity, so that at the end of 30-34 min the settleable solids are about 300 mg/liter. If the test is continued for another hour, the sludge comes to the surface in typical rising sludge fashion. This is not a case of filamentous bulking as indicated by microscopic examination, the clear supernatant observed in the settleable solids test, and the sludge volume index of approximately 80 mg/g. Another indication of anaerobic denitrification as the cause of the floating sludge is the repeated observation of very low DO levels in the clarifier. This problem has been accentuated since a portion of the plant aeration capacity was diverted to the ammonia-stripping lagoon, although this is being rectified by bringing another compressor on-line.

Cost Data

Costs incurred during the operation of the biological units are indicated in Table 13. The operation and maintenance costs are shown for the operational period following the initial start-up phase.

The data indicate a cost of $5.12 per thousand gallons treated. The high power costs reflect the demand for electricity for leachate pumping, effluent pumping, and maintenance of the laboratory in addition to the requirements for actual treatment. In the future, it will be necessary to separate these power costs, in order to more accurately determine the cost of treatment. The labor requirement is approximately 20 man-hours per week.

SYSTEM 2. CHEMICAL/PHYSICAL TREATMENT

This discussion is presented in two parts. The first consists of the results associated only with lime treatment, and the second includes the ammonia stripping lagoon. Full-scale data were collected for System 2 without the lagoon during the periods December 11, 1975 to January 12, 1976 and June 14, 1976 to August 31, 1976, all dates inclusive. The results of this phase of the treatment plant operation are summarized in Table 14.

Table 13

OPERATION AND MAINTENANCE COSTS INCURRED DURING THE OPERATION OF SYSTEM 1 FOLLOWING ACCLIMATION OF ACTIVATED SLUDGE

Characteristic	Operational Period
Total Flow, gal	309930
cu m	1173
Lime used, lb	29650
lb/1000 gal	95.7
kg/cu m	11.5
Sulfuric acid, gal	213
gal/1000 gal	0.687
liter/cu m	0.687
Phosphoric acid, gal	26.4
gal/1000 gal	0.0852
liter/cu m	0.0852
Costs, $/1000 gal	
Power	$1.26
Lime	2.87
H_2SO_4	.57
H_3PO_4	.21
Total	$5.12

Table 15 presents the changes in each parameter attributable to the lime treatment. In very approximate terms, the lime precipitation/clarification sequence, System 2a, removed (see Column 7, Table 14) one-third of the dissolved solids and nitrogen; one-half of the organic matter, hardness and alkalinity; three-quarters of the suspended solids; and ninety percent of the phosphates. The removal of heavy metals was one-third of cadmium, one-half of chromium and nickel; two-thirds of the lead and mercury; three-quarters of the copper and over ninety percent of the iron and zinc. The increase in sulfate is due primarily to contaminants in the chemicals, although oxidation of sulfides may contribute somewhat. In other words, this section of the system performed as expected in pre-treating the leachate prior to biological treatment.

The results of the overall chemical/physical section including the lagoon (System 2b) are listed in Table 14 which shows the basic statistical relationships. Treatment performance in terms of percent removal efficiency of the lagoon alone and in conjunction with lime treatment are also seen in Table 14. The primary goal of the lagoon was achieved as the concentration of ammonia-N was reduced to 317 mg/liter, a level which was found to be tolerable for purposes of biological waste treatment. A splash plate, which was installed on August 9 to promote air/water contact, did not produce an appreciable effect on lagoon ammonia removals.

Many parameters other than ammonia were altered while in the lagoon. There was some stabilization of organic matter as shown by the reductions in BOD, COD and dissolved solids. This was mediated by biochemical processes and the increase in suspended solids is related to the growth of microorganisms, as are the reductions in sulfate and phosphate. The reduction in alkalinity and pH is most likely due to aeration effects although nitrification reactions may partially contribute to the observation. The reduction of hardness, calcium and magnesium are related and may be explained by the formation of calcium and magnesium carbonates. In this form, these would not be detected by the usual tests. Most of the other changes noted in the lagoon effluent vs. lagoon influent comparison are due to the limitations of the experimental techniques or to the radically variable nature of the raw leachate.

The overall treatment efficiency of the complete chemical/physical section is summarized in Table 14. These data do not include the effect of neutralization. The values in the last column (Column 14) represent removal efficiencies for the lime precipitation/sedimentation/ammonia stripping sequence. In terms of organic matter, 56.1 and 56.7 percent of the BOD and COD are removed, respectively. Approximately sixty percent of the ammonia-N and total kjeldahl nitrogen are removed. The removal of suspended solids, alkalinity and hardness is about two-thirds. The removal of metals was as follows: 50-65 percent removal of cadmium, nickel and mercury; 70-80 percent of chromium and copper; 88 percent of lead; 95 percent of zinc; and 99 percent of iron.

Table 14

SUMMARY OF SYSTEM 2 RESULTS. EACH SYSTEM CONSISTS OF LIME TREATMENT AND CLARIFICATION. SYSTEM 2a and 2b ARE WITHOUT AND WITH AIR STRIPPING OF AMMONIA, RESPECTIVELY.*

Parameter	System 2a							System 2b							Lagoon Only
	Influent			Effluent				Influent			Effluent				
	n	$\bar{x}$	cv	n	$\bar{x}$	cv	R	n	$\bar{x}$	cv	n	$\bar{x}$	cv	R	R
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Alkalinity, as $CaCO_3$	23	5705	0.23	25	3182	0.26	44.2	10	5235	0.35	10	1572	0.15	70.0	49.5
Ammonia-N	23	1989	1.14	26	1245	1.15	37.4	10	763	0.23	12	317	0.11	58.5	40.8
BOD-5	26	5462	0.60	25	2692	0.52	50.7	12	6001	0.61	12	2632	0.27	56.1	23.0
Cadmium	20	0.046	0.39	22	0.03	0.43	34.8	10	.044	0.52	10	.0207	.48	53.0	22.2
Calcium, as $CaCO_3$	21	709	0.31	23	645	0.71	9.0	10	749	0.39	10	448	0.22	40.2	16.2
Chloride	19	5577	0.55	21	4265	0.77	33.5	10	4340	0.36	10	3167	0.12	27.0	-6.2
Chromium	21	0.169	0.56	23	0.090	0.59	46.7	10	0.138	.62	10	0.04	.50	71.0	28.3
COD	76	11419	0.40	74	5782	.42	49.4	43	9920	.23	47	4295	0.13	56.7	19.3
Copper	21	0.489	0.81	23	0.108	.53	77.9	10	.646	.79	10	.098	.82	84.8	10.3
Dissolved Solids	93	11533	0.25	90	7615	.28	34.0	44	10324	0.18	45	5428	0.08	47.4	14.3
Hardness, as $CaCO_3$	21	5460	0.34	23	2716	0.57	50.3	10	5115	0.33	10	1796	.40	64.9	13.1
Iron	21	267	0.65	23	4.9	3.18	98.2	10	226	0.77	10	2.21	1.14	99.0	-51.5
Kjeldahl-N	20	1975	1.33	23	1227	1.39	37.9	10	761	0.36	11	326	0.12	57.2	39.5
Lead	18	0.53	0.60	20	0.18	0.72	66.0	7	0.54	0.89	7	0.061	.49	88.7	-76.0
Magnesium, as $CaCO_3$	21	692	0.50	22	254	0.95	63.9	10	57[illegible]	0.26	10	163	.82	71.7	7.6
Mercury	16	0.011	0.90	18	0.0039	1.13	64.5	10	.015	0.60	10	.007	1.14	53.3	27.0
Nickel	21	0.57	0.33	23	0.28	0.36	50.9	10	.597	0.43	10	.23	.21	61.5	2.5
pH	106	7.13	--	107	9.25	--	--	55	7.22	--	56	8.59	--	--	--
Phosphates	21	2.80	0.63	22	0.34	2.12	87.9	10	2.39	0.66	10	0.03	1.33	98.7	65.4
Potassium	19	1035	0.26	21	721	0.26	30.3	8	1080	0.19	8	639	0.09	40.8	-1.3
Sodium	21	1275	0.24	23	862	0.29	32.4	10	1240	.23	10	751	.13	39.4	-2.9
Sulfate	20	126	0.88	22	477	1.02	--	10	110	1.05	10	257	0.18	--	7.1
Suspended Solids	92	1450	0.65	89	403	0.75	72.2	44	1240	0.77	45	430	0.65	65.3	-32.8
Total Solids	9	11154	0.30	10	6718	.20	39.8	9	11154	0.30	10	5779	0.01	48.2	--
Zinc	21	9.59	.65	23	0.59	1.58	93.8	10	6.01	0.65	10	0.276	0.36	95.4	48.2

*All units are mg/liter except pH which is express in pH units. R stands for percent removal. System 2a effluent is the lagoon influent.

Table 15

SUMMARY OF EFFECTS OF CHEMICAL/PHYSICAL TREATMENT*

	Influent	Lime Treatment Effluent	Lagoon Effluent+
Suspended Solids	1994	403	430
Dissolved Solids	11190	7615	5428
Total Solids	11154	6718	5779
COD	11210	5782	4296
BOD	4458	2692	2632
Alkalinity	5685	3182	1572
Hardness	5116	2716	1796
Magnesium	652	254	163
Calcium	651	645	448
Chloride	4816	4265	3167
Sulfate	114	477	257
Phosphate	2.81	.34	.03
Ammonia-N	1966	1245	317
Kjeldahl-N	1660	1227	326
Sodium	1177	862	751
Potassium	959	721	639
Cadmium	.04	.03	.021
Chromium	.16	.09	.04
Copper	.44	.11	.10
Iron	245	4.9	2.21
Nickel	.53	.28	.23
Lead	.52	.18	.06
Zinc	8.70	.59	.28
Mercury	.007	.004	.007
pH	7.06	9.25	8.59

*The influent data are those collected during the entire operational period, whereas the effluents figures refer to those periods when the specific units were operating.

+All units are mg/l except pH which is expressed in pH units.

Chian and DeWalle[16] have formed an hypothesis, which is summarized in Table 6, concerning the treatability of raw leachate. The BOD/COD ratio observed in the study (Column 2 of Table 14 of the leachate was 0.48 and the average COD was 11,419 mg/liter. Thus, according to Chian and DeWalle, the leachate treatment efficiency obtainable with lime should be poor to fair. In this study (Column 7, Table 14) the lime treatment efficiency for BOD and COD has been about fifty percent. Hence, in terms of the removal of organics, the Chian and DeWalle[16] hypothesis is supported. However, it must be mentioned that their hypothesis did not include the removal of heavy metals, and that the lime treated heavy metal removals have been good to excellent at the facility.

An additional effect of the ammonia stripping lagoon is the equalizing effect which, as noted by LaGrega and Keenan[23], can be measured in terms of both flow variability and quality fluctuations. The presence of the lagoon has allowed the operator to control the flow leaving the lagoon by control of the pump settings. This has provided flow equalization to the biological units. The increased uniformity of the nature of the waste can be seen in Columns 10 and 13 of Table 14 which show the changes in the coefficient of variation through the chemical/physical section of the plant. The coefficient of variation is the ratio of the arithmetic mean to the standard deviation, and as such is a measure of the dispersion of the data about the mean. The coefficient, which increases as variability increases, exhibits a general decrease through the lagoon. This is seen for all parameters except phosphate, cadmium, chromium, copper, iron, magnesium, hardness and mercury, for which the data become more variable through the lagoon. This is not entirely unexpected. The concentrations of some of these parameters are near the detectable limit, and hence variability may be high. The observation that several of these are heavy metals has not been satisfactorily explained.

Operational Comments

The primary operational factor has been the chemicals required for precipitation and neutralization. A summary of these is presented in Table 16. The rows labeled, average applied dose, have been calculated by omitting those days on which chemicals could not be added because of equipment malfunctions.

Cost Data

The cost of materials and electricity is appended to Table units are given in terms of dollars per one thousand gallons of leachate treated. The cost has been $2.80-$3.24 per thousand gallons. The power costs are quite high, reflecting energy consumption not only for chemical treatment, but also for leachate pumping, air compressors and the laboratory. The cost of operation has come down recently as the phosphoric and sulfuric acid requirements have dropped considerably as experience has been gained. Manpower costs for operation and maintenance is approximately twenty hours per week.

Table 16

SUMMARY OF OPERATION COSTS DURING EVALUATION OF SYSTEM 2

	During Operation Without Lagoon	During Operation With Lagoon
Flow, average gpd	23,487	19,897
lpd	88,908	75,318
total gal	4,227,736	1,571,875
total cu m	16,002	5,950
Lime, average applied dose,		
lb/1000 gal	28.6	40.1
kg/cu m	3.43	4.81
total lb	105,455	63,050
kg	47,877	28,625
H_2SO_4, average applied dose,		
gal/1000 gal	0.55	.64
l/cu m	0.55	.64
total gal	1,525.1	978
total liter	5,773	3,702
H_3PO_4, average applied dose,		
gal/1000 gal	.094	.099
l/cu m	.094	.099
total gal	199.9	152.1
total liter	757	976
Costs, $/1000 gal.		
Power	$1.26	$1.26
Lime	.86	1.20
H_2SO_4	0.45	0.53
H_3PO_4	.23	.25
Total	$2.80	$3.24

SYSTEMS 3 and 4

These treatment sequences were tested in full-scale during the late winter and early spring of 1976. Severe problems were encountered in achieving successful treatment. The primary reason underlying these problems was the inability to develop a healthy activated sludge. Approximately eight weeks were allocated to attempts to adapt a sewage activated sludge culture to the raw leachate. After this did not succeed, an investigation revealed that growth of activated sludge was not possible because of ammonia inhibition and phosphorus limitation. The problems were demonstrated by the observations that the average concentrations in the biological units during this time were 940 mg/liter of ammonia-N and less than one of phosphorus. The data thus indicated that in the aeration tanks, the ratio of BOD:N:P was 6620:760:1 which is in marked contrast to the usual recommendations which are in the range of 90-150:5:1.

The phosphorus limitation was investigated in two ways. First, replicate BOD tests were set up with varying additions of phosphate buffer. It was found that the BOD_5 increased with the phosphorus addition up to an upper level, indicating that, within this range, phosphorus was limiting. As a result of this finding, the BOD procedure was modified by the addition of sufficient phosphorus to overcome the limitation.

Second, a bench test was initiated to evaluate the hypothesis that phosphorus limitation was the reason for the poor development of activated sludge. The tests consisted of once daily batch draw-and-fill experiments in which the increase in settleable solids was used to monitor the growth of activated sludge. The control reactor received raw leachate only whereas the sample reactor received raw leachate plus seven ml of BOD phosphate buffer per liter of raw leachate. Thus, in the sample reactor, the BOD:N:P ratio was about 118:13.5:1. The results are summarized in Table 17. It is seen that over the short-term, there was an apparent positive impact upon the production of activated sludge and the utilization of COD. However, when the tests were continued for several weeks, it became obvious that there was no effect of phosphorus addition on either the development of activated sludge or the removal of organics.

The results of these experiments have been interpreted in the following manner. First, the biochemical oxygen demand tests, and the chemical analyses showed that the leachate was severely phosphorus limited. This problem became more serious when biological treatment followed lime addition because of the precipitation of calcium phosphate salts in that unit. Secondly, the batch draw-and-fill experiments showed that alleviation of the phosphorus limitation alone is not enough to encourage the growth of activated sludge microorganisms. It was concluded it would be necessary to reduce ammonia concentrations to a non-inhibitory level before successful biological treatment could be achieved. Consequently, the ammonia-stripping lagoon was started up prior to evaluating System 1.

Table 17

Results of Batch Draw-and-Fill Activated Sludge Experiments to Determine the Extent of Phosphorus Limitation. Results show growth of activated sludge as ml settleable solids per liter, and COD as mg/liter.

BOD:N:P / time, days	Control 6620:760:1			Sample 118:13.5:1		
	influent	effluent		influent	effluent	
	COD	COD	SS	COD	COD	SS
0	12813			12813		
1	7704			7704		
2	9339			9339		
3	--			--		
4	8388		26	8388		40
5	12868	10698	20	12868	7597	40
6	10193		15	10193		35
7	11603			11603		
8	NR			--		
9	9912			9912		
10	--			--		
11	5963			5963		
12	9012	7115		9012	7115	
13	13174			13174		
14	8606			8606		
15	8221			8221		
16	NR					
17	--			--		
18	6349			6349		
19	--	5625		--	5469	

SYSTEM 5

Although as yet incomplete, studies of the potential of carbon absorption for leachate treatment have been undertaken. The results of the evaluation of carbon treatment of raw leachate are presented here. Any testing of the process as an advanced waste treatment technique has been postponed until the beginning of the second year.

The preliminary evaluation of this system (System 5) has been carried out for raw leachate treatment. These data are presented in Table 18. These tests have been performed with an upflow column of depth 0.3 m and diameter 0.46 m, containing 15.9 kg of granular activated carbon. The influent flow was 38 liter/min, thus providing a hydraulic loading rate of 232 liter/min/sq m. As shown in Table 18, no appreciable treatment can be attributed to the carbon treatment. It should be noted that excessive suspended solids loading and influent variability contributed to this finding. The effect of the solids is to cause blockages and hence reduce process efficiency. The influent was not constant during any of the tests because it was drawn from the actual plant influent. Therefore it is impossible to calculate removal efficiency. However, it is evident from Table 18 that no renovation is occurring in the carbon columns. Hence, it is concluded that carbon adsorption is not appropriate when applied to raw leachate, although, as mentioned above, it may be suitable for final effluent polishing.

Table 18

SUMMARY OF RESULTS OF CARBON ABSORPTION TREATMENT OF RAW LEACHATE

SS = suspended
TS = total
DS = dissolved
TVS = total volatile solids

Expt #	Parameter	Sample Number 1	2	3	4	5	6	7	8	9	10	11
1	time, min	0	5	10	15	20	25					
	total flow, gal	0	50	100	150	200	250					
	pH	8.31	7.90	8.05	8.09	8.13	8.11					
	SS	2880	2280	2940	2870	3040	3060					
	DS	10570	10490	9280	10240	10270	9130					
	TS	12950	12770	12220	13110	13310	12190					
	TVS	4240	4040	3480	4180	4710	--					
	COD	4450	3840	7040	5600	6400	5760					
2	time	0	5	8	11	14	17	20	23	26	29	32
	gal	0	50	80	110	140	170	200	230	260	290	320
	SS	980	640	880	550	710	810	430	100	410	210	20
	DS	10600	10450	10410	10350	10340	10320	10740	10360	10270	11240	11150
	TS	11580	11090	11250	10940	11050	11130	11170	10460	10680	11450	11170
	TVS	5120	3950	4330	4150	4780	5070	4480	3570	4579	4190	4230
	COD	8645	7212	8460	8460	8226	9634	8772	7992	9142	9162	9844
3	time, min	0	10	13	16	19	22	25	28	31	34	37
	total flow, gal	0	100	130	160	190	220	250	280	310	340	370
	SS	820	540	380	340	570	370	900	880	630	740	430
	DS	11100	11000	11200	10730	11330	11490	10670	10010	11080	10340	10970
	TS	11920	11540	11580	11070	11900	11880	11570	10390	11710	11110	11400
	TVS	5220	4930	5160	4540	5180	5170	5320	4070	4930	4710	5080
	COD	9530	9444	9921	9762	9127	10079	9603	10365	10079	11032	9841
4	time, min	0	6	12	18	24	30					
	total flow, gal	0	60	120	180	240	300					
	SS	520	420	680	780	600	530					
	DS	10060	10690	11100	9890	10100	10240					
	TS	10580	11110	11780	10670	10700	10770					
	TVS	4530	5330	5060	4520	4600	4870					
	COD	4840	10784	9840	9840	9600	9840					
5	time, min	0	2	8	14	20	26					
	total flow, gal	0	20	80	140	200	260					
	SS	770	500	960	540	760	740					
	DS	10460	10130	10070	10590	10340	11040					
	TS	11230	10630	11030	11130	11100	11780					
	TVS	5010	4360	4320	4730	4670	5020					
	COD	10013	9170	9365	9328	10119	10040					
6	time, min	0	6	12	18	24	30					
	total flow, gal	0	60	120	180	240	300					
	SS	1120	1020	1020	1390	1210	1040					
	DS	10040	9400	10270	10140	9630	10220					
	TS	11160	10420	11290	11530	10840	11270					
	TVS	6440	6170	6990	5790	4060	6180					
	COD	8833	9723	9565	8142	9939	7960					

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Conclusions

1. The GROWS landfill leachate is characterized by high organic strength and by large day-to-day variations.

2. Considerable experience has been gained in the operation of activated sludge units on raw leachate and on leachate which has received chemical/physical treatment. It has been tentatively concluded that this raw leachate must be pre-treated in order to render it amenable to activated sludge processing. The results indicate that the raw leachate inhibits the growth of the activated sludge microorganisms. Although the presence of heavy metals and low levels of phosphorus contribute to this inhibition, it is clear that the excessive concentrations of ammonia-nitrogen are primarily responsible. At the conclusion of the current operational mode (Spring 1977), biological treatment of raw leachate will again be attempted.

3. Although the operation of the chemical/physical units will continue for some time in order to gain experience under a wider variety of operating conditions, sufficient data have been collected to provide an evaluation of this method of treating raw leachate. Lime treatment alone provides removal efficiencies of approximately 50 percent of the organic matter, 75 percent suspended solids, one-third of cadmium, and at least 50 percent of the other heavy metals.

4. The complete chemical/physical treatment sequence consisting of lime precipitation/sedimentation/air stripping achieved the following levels of removal efficiency: 56-59 percent of the organic matter, ammonia-N and total kjeldahl-N; 65 percent of the suspended solids, and 50 percent or better of the heavy metals.

5. Activated sludge treatment of the effluent from the chemical/physical units has been extremely successful. It is apparent that the reduction in ammonia-N afforded by air stripping lagoon has made conditions more suitable for the growth of activated sludge microorganisms. The lagoon provides ammonia removals of approximately 65 percent resulting in activated sludge influent concentrations of 210-245 mg NH_4^+-N/liter (99 percent confidence interval). Under this condition, the activated sludge quickly adapted to the leachate with the result that effluent BOD_5 concentrations have been consistently less than 100 mg/liter. Nitrifying organisms have developed and produced a nitrified effluent with very low concentrations of ammonia.

6 Overall, the treatment sequence consisting of chemical/physical (lime precipitation, sedimentation, air stripping, and neutralization) followed by activated sludge has produced an excellent final effluent with the following characteristics:

1. Organic matter has been reduced to 61 mg BOD_5/liter. This corresponds to 99 percent removal. The corresponding COD removal efficiency is 94 percent. The effluent BOD to COD ratio is 0.11.

2. The effluent ammonia concentration is 47 mg/liter, representing 91 percent removal.

3. Heavy metals are found in the effluent at the following levels (percent removals are shown in parentheses): 0.014 mg cadmium/liter (71.4 percent); 0.075 mg chromium/liter (28.6 percent); 0.078 mg copper/liter (75.1 percent); 0.96 mg iron/liter (99.5 percent); 0.12 mg lead/liter (78.0 percent); 0.004 mg mercury/liter (73.3 percent); 0.27 mg nickel/liter (48.1 percent); 0.44 mg zinc/liter (87.9 percent).

VI. PROGRESS EVALUATION

The original work schedule for completion of project is shown in Figure 6. With only minor alterations, this schedule has been followed closely. A few changes are suggested in this Chapter. These changes take the form of shifting emphases in light of what has been accomplished and learned during the first year of the project. Referring to Figure 7, one can see the work actually accomplished to date. This includes at least a preliminary evaluation of each of the systems to be studied.

Systems 1 and 2, i.e., those with chemical/physical treatment as the first step, have been evaluated and the results are very encouraging. In fact, the success achieved during the summer of 1976 has been so promising that we propose to continue operating in this mode for the next six months. We make this proposal in order to obtain data over a wider range of realistic operating conditions, especially those of higher flows and lower temperatures expected during the next half year. These results will be supplemented with bench testing, which is presently being initiated. The purpose of the bench-scale experiemental program is to develop kinetic information which can be applied to full-scale design of chemical/physical and biological units in the future.

Systems 3 and 4 have received preliminary evaluation in tests conducted during months four to seven. These treatment sequences are those in which the activated sludge process receives raw leachate. As indicated in Chapter VI, the results indicated that the chemical environment afforded by the raw leachate was a hostile one which would not permit the growth of activated sludge microorganisms. It was concluded from the data that ammonia toxicity was responsible for inhibiting the activated sludge. However, low ambient temperatures may have contributed to these findings. Consequently, during the Spring of 1977, Systems 3 and 4 will be reevaluated.

During the coming months, it is proposed that increased emphasis be placed on bench-scale testing including System 5. As mentioned above, this information will be used to develop kinetic and design criteria and to optimize operational parameters. The bulk of this work will be focused on System 1 because the data collected indicate that treatment effluent criteria can be readily reached with chemical/physical treatment followed by activated sludge.

The changes in the emphasis of the experimental program outlined in the above paragraphs are reflected in Figure 8. In this chart, it is seen that bench-scale studies and operation of Systems 1 and 2 will continue for the next six months, and that Systems 3 and 4 will be reevaluated during months eighteen through twenty-three.

It is apparent that there is sufficient technical justification for extension of the project period for a third year. Overall, the purpose of the demonstration project is to show in a full-size plant that chemical-physical-biological treatment of leachate is possible, to select the best treatment sequence, and to develop sound treatment cost data.

The various operational sequences of treatment have been put through their initial testing and it appears that chemical-physical followed by biological offers the best potential. However, because of the initial startup period, we should take another look at the other alternatives. Further, we have come to recognize that leachate quantity and quality transients are having a significant impact on the plant operation and, consequently, on the treatment cost data. GROWS has indicated that they would consider installation of an initial equalization lagoon to permit a more uniform input of leachate. Whether or not they would authorize such a lagoon depends substantively on the decision with regard to a third year.

Based on our operating experience to date, there are several factors which we believe should be evaluated in a third year. The results of a third study year would greatly enhance the quality of the final results of the demonstration project. These factors are briefly outlined below.

1. By construction of the equalization lagoon, flow and quality characteristics would be smoothened, thereby developing a quasi-steady state treatment process. This effect would allow for a better definition of the relationship between treatment cost and leachate quality. The third year may be used to separate the total power costs into the component parts: raw leachate pumping, aerators, other treatment requirements and final effluent pumping.

2. An extended evaluation of leachate treatment using the process sequence scheme which has the most potential will clearly indicate impact on treatment cost of changes in quantity, quality and seasons.

3. Some bench scale studies have been performed during the first two project years; a third year would allow for a full-sized plant assessment of the pilot plant results.

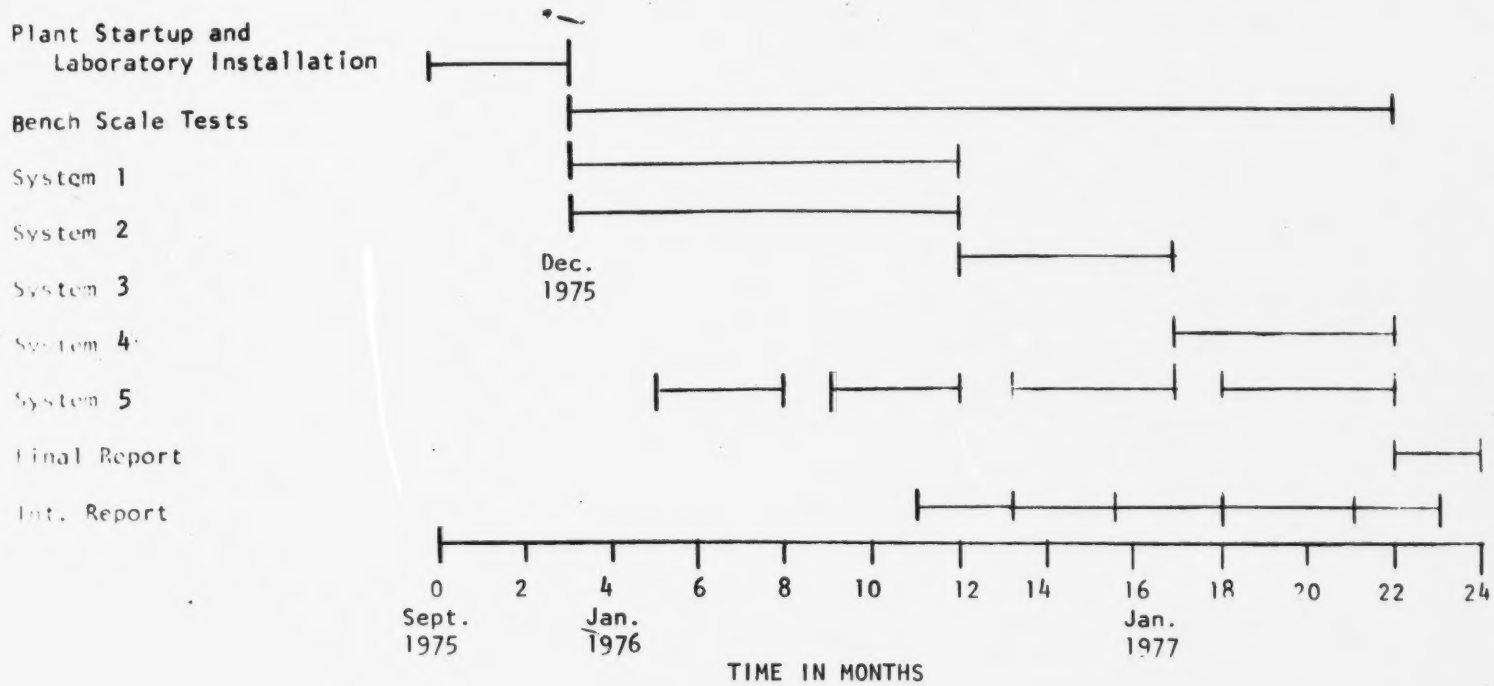
4. A third year would permit the time necessary to optimize plant operation, using the selected scheme, by developing techniques to maximize removal and minimize operating costs.

5. A third year would allow for gathering of additional information to refine design criteria.

6. A third year would allow for a full scale investigation of the potential for operating the plant to maximize the removal of

specific contaminants, such as particular heavy metals, and to minimize operating costs. (i.e., pH adjustment based on metals present).

Figure 6
WORK SCHEDULE FOR COMPLETION
OF PROJECT



System 1 - Chemical-Physical followed by Biological

System 2 - Chemical-Physical

System 3 - Biological followed by Chemical-Physical

System 4 - Biological

System 5 - Carbon Adsorption

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Figure 7. WORK ACCOMPLISHED DURING FIRST YEAR OF PROJECT

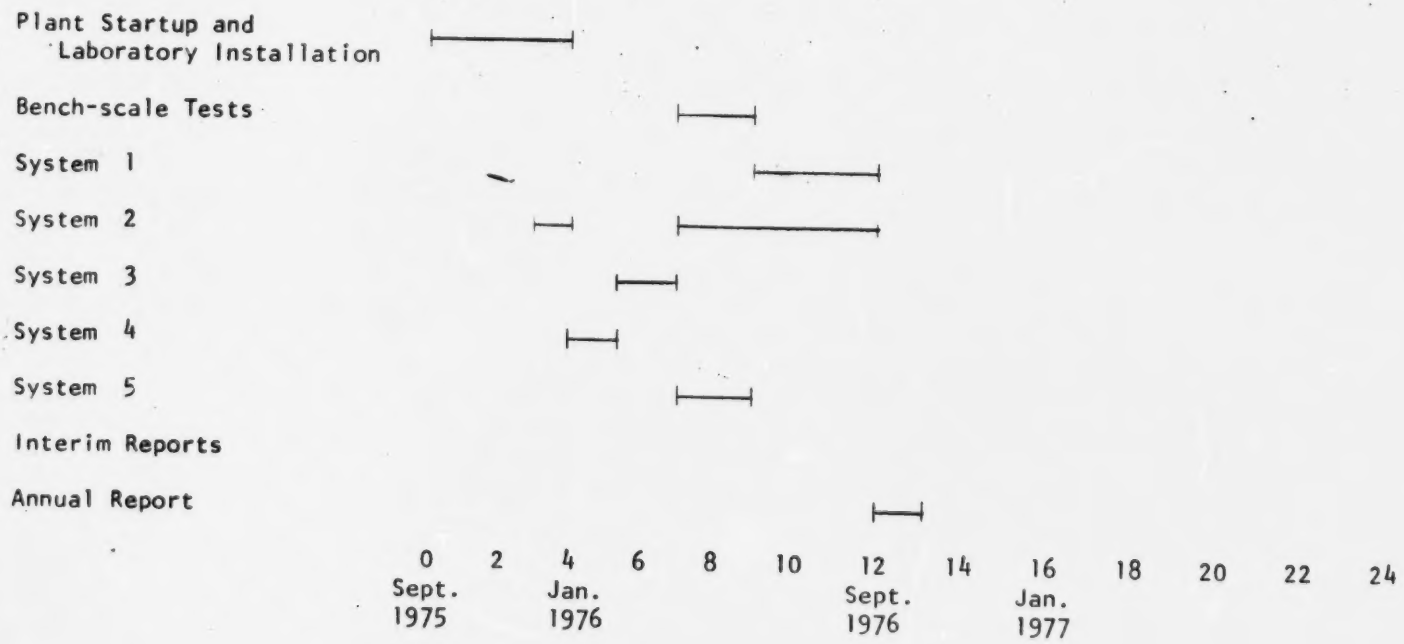
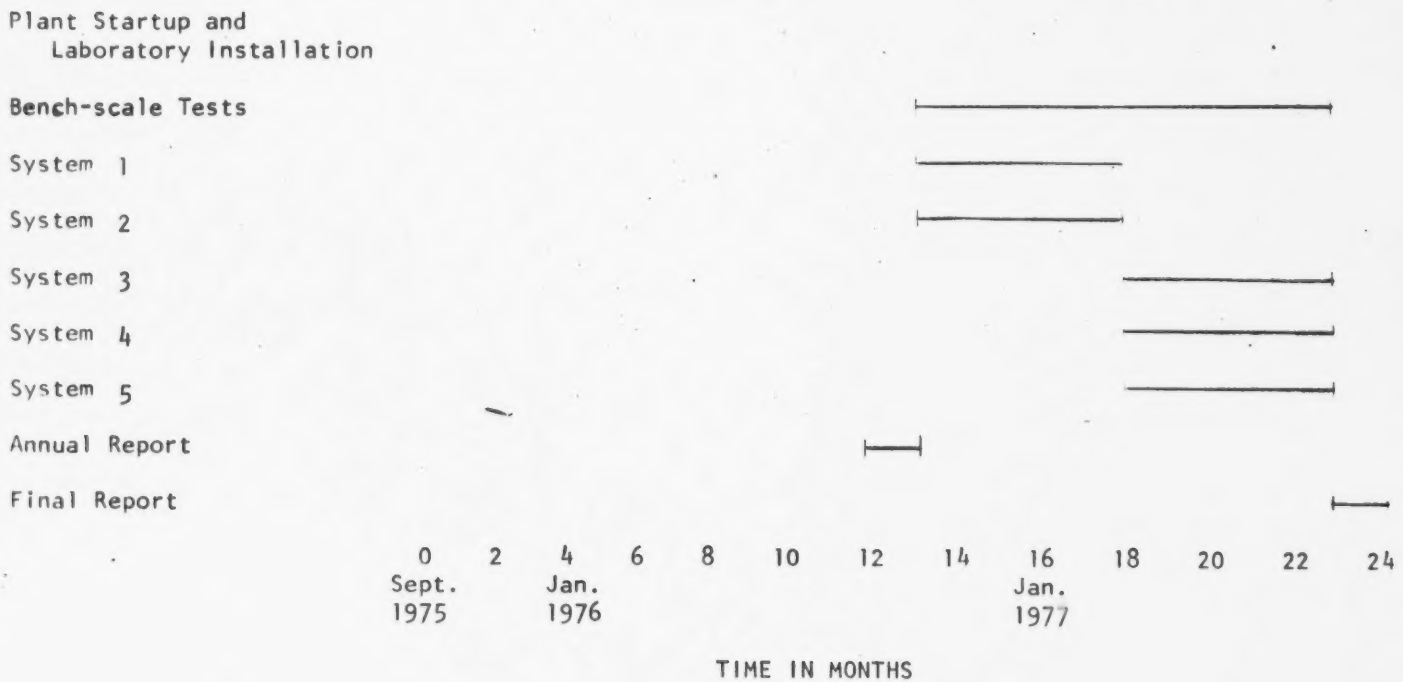


Figure 8. PROPOSED WORK FOR SECOND YEAR OF PROJECT



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APPENDIX

LEACHATE TREATMENT PLANT OPERATION AND MAINTENANCE ROUTINE

Although the profession has considerable experience in the operation of chemical/physical and biological treatment processes, there is no literature relative to the operation of leachate treatment plants. It is for this reason that the following section has been prepared. It is hoped that this information will prove valuable in the operation of the leachate treatment plants that are sure to follow.

CHEMICAL/PHYSICAL UNITS

Lime Treatment

The lime handling equipment receives routine operator attention for the following: twice daily backwash of lime pumps and three times daily addition of lime to the hopper. The lime slurry lines are checked daily where they enter the clarifier to ensure the free flow of lime slurry. Lime is received about twice per week in shipments of two pallets which are unloaded and the sacks stored. Maintenance of the lime pumps is carried out at weekly intervals. This consists of removing all lines from the pump, draining them and looking for blockage. The piping is backwashed for about five minutes, and any lime which has settled out in the lime slurry bin is broken up and dispersed.

Additional maintenance for the lime system is performed routinely at monthly intervals. The lime slurry bin is drained completely using the barrel transfer pump. This has to be done three or more times to remove most of the material. Any additional residue is scooped out. Hardened lime is chipped and scraped away from the sides, pipes, and mixer blade. Both lime pumps are disconnected, all pipes to the lime bin are removed, cleaned and backwashed. Ordinarily, some pipes are replaced and new fittings are often needed. Lime is chipped out of the pump impellors which have a tendency to work loose, and therefore need tightening. Lime slurry pipes from the pumps to the clarifier generally need to be replaced every month due to lime coating resulting in excessive hydraulic resistance. The float valve in the lime slurry bin must be completely cleaned and lubricated, and it must be replaced frequently.

Clarifier

The clarifier in the chemical/physical section has been relatively maintenance-free. On a routine basis at monthly intervals, it is necessary to remove excess sludge. This is done by drawing down the clarifier about 2,000 gal. in order to bring the level below the bottom of the center rings. The rings are washed out, and the thick hardened material is chipped away from the mixer blade. The clarifier screw

gear box and the clarifier mixer are checked monthly for oil. At weekly intervals, the one fitting on the clarifier mixer and three on the clarifier drive are greased. Generally, 500 gal of primary clarifier sludge are wasted daily. Sludge is either pumped directly into a tank truck or into the sludge holding tank. In the latter case, it is subsequently air lifted or pumped to the tank truck. The truck is filled and the sludge returned to the landfill approximately two or three times per week. This includes any sludge wasted from the biological units.

Lagoon

The flow from the lagoon to the biological unit is checked daily and is usually adjusted because of influent flow changes. The level in the lagoon increases radically the day after a heavy rain. Variations in the flow rate to the biological unit are made on the basis of maintaining the flow as constant as possible without permitting the lagoon to empty or overflow.

Acidification

Acid solutions are prepared on an as needed basis. The general procedure is to add sulfuric acid to a half tank of water by pumping from the acid barrel with a transfer pump using a one inch hose. At the present time, the sulfuric acid is added only as needed. The phosphoric acid solution is prepared by the addition of two gallons to a tank of water, and this lasts for two days. The acid pump is checked and oiled monthly. The check valves are usually replaced at this time. The acid tank is drained with the barrel transfer pump and any sediment is swept out. The tubing and back pressure valve are also inspected.

BIOLOGICAL UNITS

Aeration Tanks

The froth spray nozzles are observed daily and cleaned as necessary. It is necessary to check the return sludge line and the scum line. These air lifts are very sensitive to variations in the air pressure, and they are usually off if the blower has previously shut down. The blowers are checked periodically and, at monthly intervals, they are greased and oiled, and the condition of the belts is noted.

Secondary Clarifier

The surface of the clarifier is cleaned as needed. This is usually at weekly intervals. The floating material concentrates between the weirs and the effluent baffles from which it must be removed before it builds up, overflows the weir and degrades the effluent. Sludge from the biological unit is wasted as it becomes necessary.

DATA COLLECTION

Each day at noon, the operator takes meter readings of electricity consumed, volume of effluent treated and volume of influent pumped from each manhole. The calibration of these readings is occasionally rechecked as discrepancies have been noted. Samples are collected for the daily tests: chemical oxygen demand, dissolved solids, suspended solids, pH, settleable solids, total solids, volatile suspended solids, dissolved oxygen and temperature. These samples are collected from the raw leachate, clarifier effluent, lagoon, mixed liquor and final effluent. Weekly samples are obtained from the same set of sampling points, and are analyzed, in addition to the daily tests, for the following: 5 day biochemical oxygen demand, sulfate, ortho-phosphate, chloride, alkalinity, ammonia nitrogen, organic nitrogen, kjeldahl nitrogen, hardness, sodium, potassium, magnesium, calcium, and the heavy metals cadmium, chromium, copper, iron, lead, mercury, nickel, and zinc. The atomic absorption spectrometer is used for the heavy metals, and it must be dismantled and cleaned after each use.

GENERAL MAINTENANCE

This includes general cleaning of the laboratory, plant and grounds, repair of leaks, etc. There are other pumps not mentioned above which need grease and oil on a routine schedule. These pumps are for sodium hydroxide and chlorine, and for the final effluent. In addition, the various equipment in the laboratory must be properly maintained.

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